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JULY 1986
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Smart cards

Solar cells

Wally Rhines (left) and George Heilmeier of Texas Instruments

NEC NEWSCOPE

NEC INTRODUCES WORLD'S FASTEST FLOATING-POINT SIGNAL PROCESSOR.

Our μPD77230 Advanced Signal Processor breaks the floating-point barrier in digital signal processing (DSP) with unprecedented speed and accuracy.

The new single-chip CMOS DSP races through 32-bit full floating-point arithmetic at 13.4 MFLOPS. It executes up to 6 concurrent operations, including multiply and accumulate, in a 150ns cycle.

With 32-bit floating-point precision, our advanced signal processor eliminates problems with round-off error, quantization noise, scaling, limit cycles and over/underflow. It is unique in offering a 55-bit multiplier result (8-bit exponent, 47-bit mantissa), with eight 55-bit registers, 47-bit ALU and barrel shifter.

In addition to its large internal memory blocks (512 × 32 × 2 data RAM, 2K × 32 program ROM and 1K × 32 data ROM), the 77230 provides external expansion up to 4K of program RAM and 8K of data RAM. Serial and parallel I/O also add flexibility. The serial interface allows cascading, links with codecs and AD converters while the parallel interface supports master- and slave-mode operations.

The 77230 is ideal for image processing, graphics workstations, telecom and other applications requiring high speed and high precision.

C&C
Computers and Communications

NUMBER 135

NEW ZEALAND GOES DIGITAL WITH NEW FOTS AND NEAX61.

Plans for a nationwide Integrated Digital Network (IDN) in New Zealand, where the telephone ownership rate is among the highest in the world, are rapidly taking shape.

The New Zealand Post Office selected NEC to supply state-of-the-art 140MB fiber optic transmission systems (FOTS) and digital switches that will bring the digital future clearly into view.

NEC will provide all the necessary optical terminal and repeater equipment for the fiber optic systems to be installed in links covering Wellington, Auckland, and other major cities.

NEC's 140MB FOTS provides high-quality communications paths equivalent to 1,920 telephone channels. High-performance optical devices enable long repeater span.
It also features in-service system monitoring functions, low power consumption and compact size. A slim rack, measuring 2.75m(H) × 0.12m(W) × 0.225m(D), accommodates three terminal systems.

For the development of its ISDN, the New Zealand Post Office selected NEC's enhanced NEAX61 digital switching system with ISDN capability. Nearly 100 systems, including toll and international switches, are to be supplied within a five-year period.

NEAX61 digital switches with an aggregate total of 5 million lines are now in service in 36 countries.

NEC TRANSPONDERS SELECTED FOR INMARSAT-2.

NEC satellite transponders will play a key role in INMARSAT-2, the second generation of international maritime communications satellites.

NEC was recently awarded a contract from British Aerospace Public Limited Company to supply TT&C C-band transponders. This technology-intensive equipment is used to receive and demodulate telecommand signals, to transmit telemetry signals, and for ranging.

The transponder design will include various leading-edge technologies such as low noise amplifiers (Noise figure: 2.5dB), SAW filters to achieve excellent band-rejection performance (60dB min. ±2MHz from center frequency), threshold extension FM demodulation to achieve high sensitivity, and hybrid microwave ICs to minimize equipment size and weight, plus high-efficiency high-power amplifiers (RF output: 6W min.).

As one of the world's leading suppliers of satellite transponders, NEC has contributed to a number of international programs, supplying hundreds of advanced transponders for INTELSAT-IV, IV-A and VI series of communications satellites.

NEC has also integrated and supplied all the transponders for Japan's communications satellites, including the world's first two Ka-band satellites, and various TT&C (tracking, telemetry and command) transponders.

Additionally, NEC was awarded a contract to develop and integrate high reliability transponders for BS-3a and -3b, Japan's next generation of direct broadcasting satellites.

ALL-SOLID-STATE UHF TV TRANSMITTERS.

The latest 30kW UHF TV transmitter from NEC sets a new standard for high output power in all-solid-state design.

The 30kW transmitter incorporates many enhancements including high-performance exciters, powerful transistor power amplifiers, low-loss RF combiners and high-efficiency switching regulators.

The 1.2kW transistor power amplifier, utilizing reliable, high-power and high-gain (120W typical and 7dB min. at 860MHz) bipolar transistors which were developed in-house, features a remarkably reduced component count—only 1.7 times larger than the conventional 300W PA.

Compared to tube types, the new transmitter features greatly enhanced economy and reliability. Safety and maintainability are also improved, while power consumption is reduced by approximately half.

NEC's new all-solid-state UHF TV transmitter series includes 15kW, 10kW, 5kW and 3kW models. A 30kW system is already in satisfactory operation.

NEC

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All comparisons are for purposes of illustration only User's application performance is dependent on application

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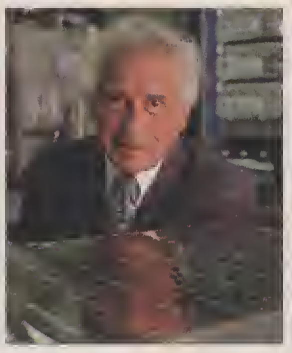

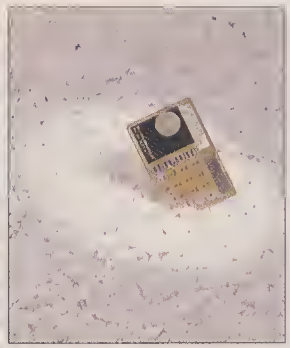

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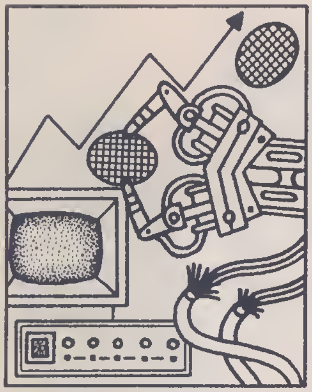
FEATURES

DEPARTMENTS

Cover On screen: Texas Instruments' Helicopter Emergency Expert System.
Photo by David Buffington.

OPINION



DAN COLLINS

Business opportunity is entering a golden age

With business news dominated by runaway federal deficits, the threat of a world banking crisis, and record trade imbalances—all against a backdrop of terrorism—it seems ludicrous to suggest that we are entering an economic golden era. Yet that scenario appears much more likely than the grim picture painted by many doomsayers in the popular press.

This new golden era of business will be far different from what transpired in the U.S. during the early part of this century, however, when the rise of steel, railroads, telephony, automobiles, and other basic industries turned the country into the world's premier economy. The coming era will be global in scope. But the colonialism that helped fuel national economies in the past will be replaced by international alliances and global corporations. This is already beginning to occur in industries like automobiles and steel, with the major players also taking positions in related industries, such as robotics or oil.

Asian nations will play a powerful role, as millions of industrious people in the Eastern world gain the skills and education needed to make their nations potent competitors in world markets. And as China continues to modernize over the next decade, an immense new marketplace—with a quarter of the world's population—will open up.

Developments in a few technologies are creating the critical mass needed to trigger this worldwide economic boom. Chip technology is progressing much faster than our skills at using it effectively. Although we still call them computers, chip-based machines will find far more powerful uses than just doing rapid calculations. We will begin to see them as intelligent assistants, information resources, and communications machines. Optical fibers will provide the wideband links needed to transfer large amounts of varied information, and optical devices will begin to perform more system functions now done by electronics. New materials, particularly ceramics and fiber composites, will lead to much more energy-efficient mechanical systems. Biotechnology will revolutionize industries such as agriculture and pharmaceuticals.

All this will create tremendous business opportunities. But the competition will be fierce. As knowledge of these new technologies inevitably spreads, it will be cleverness in putting them to work that will provide the greatest successes. And timing will be critical. New tools must mesh well with the systems they will connect to, making compatibility a major issue. And those tools that best meet users' needs, or at least seem to, will win out in the marketplace. So fasten your seat belts and get set for a rough, but exhilarating, ride into the future.

Robert Haavind

Robert Haavind

Published monthly by ***High Technology Publishing Corp.***, 38 Commercial Wharf, Boston, MA 02110.

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move into new markets.

Battelle's Center for Metals Fabrication (CMF) played a role in this modernization success. CMF is an R&D applications center sponsored by the Electric Power Research Institute, the research and development arm of U.S. electric utilities. Its goal is to synthesize and repackage technical information to help industry move forward and meet the challenges ahead.

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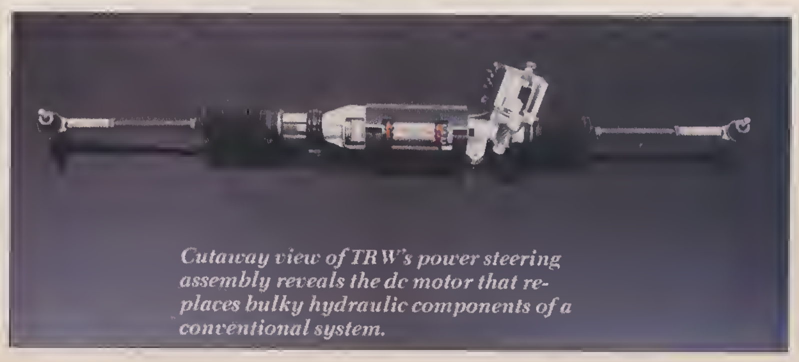

Cutaway view of TRW's power steering assembly reveals the dc motor that replaces bulky hydraulic components of a conventional system.

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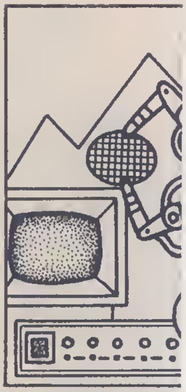
The photograph at left was omitted from the June 1986 Update "Power steering on demand."

We welcome comments from our readers. Please address letters to Editor, High Technology, 38 Commercial Wharf, Boston, MA 02110.



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Robert Haavind

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DAN COLLINS

LETTERS

Reaching investors

I work for a microelectronics market research firm that is often quoted in the media concerning new developments in semiconductor technology. Last fall I was quoted in your Business Outlook "Digital signal processors: a high-growth market" (Oct. 1985, p. 28). My firm received numerous telephone calls in response to your article. In fact, the only time we received so many inquiries from a single quote was from a *Wall Street Journal* article on integrated circuit trends.

The differences in responses from the readers, however, were significant. Although we received calls from one or two members of the financial community concerning the *Journal* article, most calls were from executive search firms looking for referrals. On the other hand, the majority of calls we received from your article were from investment bankers and venture capitalists who were genuinely concerned about the market prospects of high technology developments. Only one executive search firm called.

Although these were not statistically significant samples, you can be proud that your magazine serves as a primary information medium to many firms financing high technology ventures.

William I. Strauss, President
Forward Concepts
Tempe, Ariz.

Tuning up

"Manufacturers must face the music" (March 1986, p. 12) depicts a general lack of technological awareness by American industry. But let me sound a note of hope.

A case in point is the Peerless Saw Co. of Groveport, Ohio. This 55-year-old manufacturer has entered a new era by installing a computerized laser system that cuts industrial-grade circular-saw blades in about one-seventh the time it took to form them on a punch-press. The company has new flexibility to handle custom orders and now can move into new markets.

Battelle's Center for Metals Fabrication (CMF) played a role in this modernization success. CMF is an R&D applications center sponsored by the Electric Power Research Institute, the research and development arm of U.S. electric utilities. Its goal is to synthesize and repackage technical information to help industry move forward and meet the challenges ahead.

Thomas G. Byrer, Director
Center for Metals Fabrication
Battelle
Columbus, Ohio

Managers are not intimidated by the computer; they believe it can help them. Being against "islands of automation" may be a valid stance for General Motors, but for the average business, a 64K microcomputer on the manufacturing floor is probably an optimum first step. Programmed in a modern compact control language like Forth, it can show the flexibility and power now available without major capital commitment and allow manufacturers to become computer literate in automation and control. This leads to better decisions about going on to more integrated systems.

Carl J. Baxter, Senior Consultant
Business and Technical Consultants
Penfield, N.Y.

'Tooning up

I read "Micros get animated" (May 1986, p. 67) with interest, but was surprised that there was no mention of the Commodore Amiga. While other currently available models may demonstrate the potential of microcomputer-based animation, the Amiga, with its custom graphics chips, promises far greater sophistication and speed at comparatively low cost.

Software will be necessary to demonstrate this computer's special talents in this area. A few animation programs are now available, and several others are in the works. The first such offering, Aegis Animator, from Aegis Developments (Santa Monica, Cal.) uses "tweening" techniques [which allow the computer to fill in motions between frames and smooth the action] similar to the program you describe for the IBM PC, to allow detailed animated effects. Future software should be even more impressive.

I'm enthusiastic because I have used an Amiga extensively. I'm an engineer with the NASA Johnson Space Center in the area of mission design and development. Combined with its excellent sound capabilities, the Amiga offers great application in the area of animation and video.

Steven Lewis
Houston, Tex.

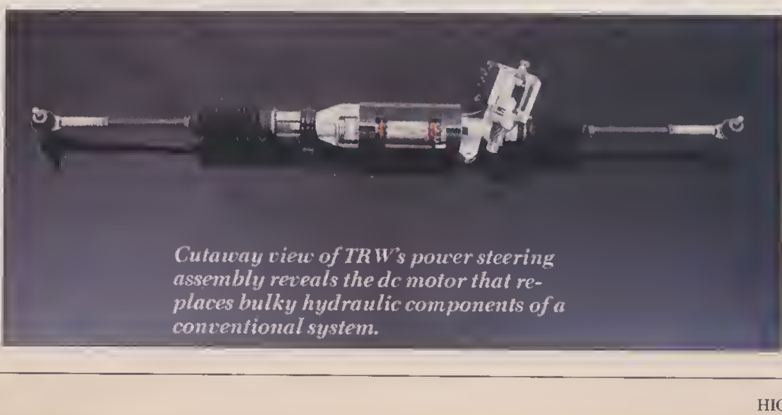
Different strokes

I read "Tomorrow's weather: New accuracy in forecasting" (April 1986, p. 27) with great interest. But the sidebar on the lightning tracking system (from Lightning Location and Protection in Tucson, Ariz.) deserves comment. There is another lightning tracking system called Lightning Position and Tracking System (LPATS) that is currently in use at the National Severe Storms Forecast Center and the National Severe Storms Laboratory. It was developed in 1982 by Atlantic Scientific Corporation under contract to the Office of Naval Research. LPATS uses a patented time-of-arrival technique to locate cloud-to-ground lightning strokes. A typical network consists of four receivers that can track lightning in an area 1800 km on a side. Accuracy is better than 250 meters in the center of the network, and falls off slowly to about 5 km at 700 km. The greatest advantage of the system is the lack of site errors so common in magnetic direction-finding systems.

Other current users of LPATS data include the National Weather Service, NASA, Martin Marietta, the Navy and the Air Force, electric utilities, and TV meteorologists.

Thomas E. Nelson, Marketing Dir.
R*SCAN Corp.
Minneapolis, Minn.

"Building a better tomato" (May 1986, p. 46) incorrectly associated Keith Walker with DNA Plant Technologies. Walker is actually vice-president of research for Plant Genetics Inc. (PGI). Also, Joe Picard's correct title is assistant marketing manager for PGI.



Cutaway view of TRW's power steering assembly reveals the dc motor that replaces bulky hydraulic components of a conventional system.

The photograph at left was omitted from the June 1986 Update "Power steering on demand."

We welcome comments from our readers. Please address letters to Editor, High Technology, 38 Commercial Wharf, Boston, MA 02110.

UPDATE

GE's solid-modeling display speeds up the design of complex structures, such as this oil-refinery piping.

Space biz 101

Until recently, the chances of finding formal instruction in space business have rivaled those of spotting a black hole. But starting this year, in response to growing interest by MBA students, Stanford Business School is offering a course devoted entirely to commercial developments in orbit.

Taught by logistics professor Gayton Germane, the course covers such topics as the evolution of the U.S. space program, the effect on business of governments' policies and goals in space, space insurance, planning policies for the Space Shuttle, and—especially relevant at present—crisis management. Guest experts from NASA and the space industry teach several of the classes, and the students visit a number of aerospace companies. "What better way to sow the seeds for commercial space opportunities than with the people who will someday be making the decisions?" asks Larry Milov, manager of the Commercial Use of Space program at NASA's Ames Research Center, who helped set up the course.

Stanford students have greeted the new course eagerly—"Space industries are today where the computer business was 20 years ago," says second-year MBA student George Macpherson—and other universities are beginning to take similar steps. Students at Harvard Business School have already studied space commercialization as part of a course in marketing, while the business schools of California State U. at Fresno and the U. of San Diego have talked to Milov about setting up their own space business courses.

Faster graphics processing

Computer-aided design has been hampered by an unpleasant tradeoff: the ability to manipulate realistic color images of 3-D objects has meant either sinking millions of dollars into a mainframe that could do the job quickly, or settling for a less costly system that was often too slow to be practical. But a graphics processor recently unveiled by GE's Silicon Systems Technology Dept. (Research Triangle Park, N.C.) appears to offer the best of both worlds. The unit works with "solid-modeling" software running on a supermicro- or minicomputer to produce perspective views of an object from any angle with surfaces shaded as they would appear under various lighting conditions. When the user amends the drawing—say, by adjusting its dimensions or rotating it—the $66,000 Graphicon 700 puts the revised image on the screen in less than a second. By contrast, claims GE, similarly priced 3-D display processors take from several seconds to several minutes to respond to such commands.

The system owes its combination of speed and modest price to several factors: custom chips that perform multiple functions, the development of a very-high-speed data bus to carry information within the system, and an innovative architecture that allows data to be retrieved and entered at the same time. The Graphicon is claimed to be as quick as today's widely used "wire-frame" display processors, which generate line drawings.

All the news that fits

Imagine a newspaper containing only the news you want to read. Just such a service is now being tested in the Boston area. In the experimental system, MIT's Laboratory for Computer Science transmits the full text of all articles carried by the New York Times News Service (which includes most of what's in the printed *Times)* and by the Associated Press as soon as they are filed. Articles are sent over an unused subcarrier of a Boston FM radio station.

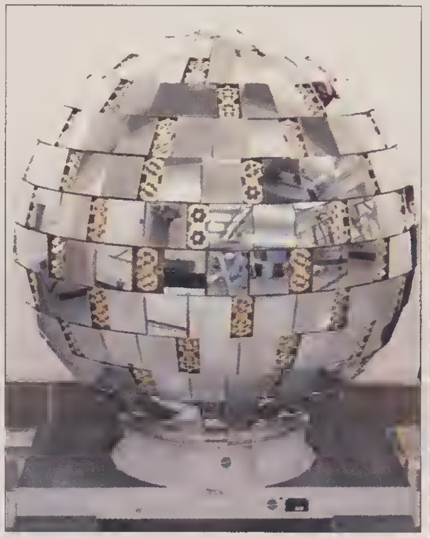
The paper's 150 subscribers plug special receivers into their personal computers to capture and store on a disk just those stories that match a list of topics entered in advance. The result is a filtered view of the world that might consist of, say, the day's lead national and international news plus any article mentioning Libya, nuclear reactors, or a company in which the subscriber owns stock. Topics can be ranked in priority; as the disk fills, the system deletes aging and low-priority stories. While of obvious benefit to professionals following fast-breaking fields, the electronic paper is also inexpensive enough to offer to consumers as a supplement to a print newspaper, says David Gifford of MIT's electrical engineering and computer science department, who directs the project. The receivers cost less than $100, he says.

Synthetic skin promotes healing

A newly patented artificial skin is being readied for testing on wound and burn victims. The nontoxic covering not only helps prevent potentially fatal infection in such patients, but reportedly promotes faster healing and reduced scarring as well. Developed by microbiologist Abe Widra at the University of Illinois at Chicago, the sticky, cellophane-like skin is produced from two natural compounds: keratin (a major component of hair and nails) and chitosan (a starchy material found in crab shells and insect skeletons).

Unlike other synthetic skins under development, which must be carefully stitched in place, Widra's covering can simply be laid over the injury—even at the scene of an accident—providing quick protection against bacteria. Absorption of body fluids quickly softens the material so that it adheres tightly to irregular shapes. The retained fluids also form a friendly environment for the disease-fighting white blood cells that rush to the injury site. Moreover, says Widra, the skin's chemical structure provides a biologically compatible template for the growth of new supportive tissue (collagen and fibroblasts) and epidermal cells. As the wound heals, the artificial skin residue gradually dries up and falls off.

Further development and commercialization of the skin (called Stra Cor, after the natural skin layer known as the stratum corneum) has been licensed to Kendall Co. (Boston), a subsidiary of Colgate-Palmolive. Kendall will conduct additional animal and human studies and will submit the results to the FDA for approval.



Mirrors and laser-reflecting prisms on geodetic satellite allow measurement of both angle and distance.

Japanese satellite will simplify mapping

This fall, Japan's National Space Development Agency will launch a satellite designed to speed up the task of mapping remote regions. Called the Experimental Geodetic Payload, the satellite is the first to combine two surveying techniques—the reflective sphere and the prismatic reflector.

In the first method, surveyors observe sunlight as it bounces off a shiny satellite. Measurements of the satellite's horizontal and vertical angles from two known points yield the location of the satellite, allowing surveyors at a third point to calculate their position through similar measurements. In the prism method, lasers are aimed at a satellite covered with arrays of prisms that return the beams to their source. Clocking the beams' round trip reveals the distance to the satellite. While this method is more accurate, it requires three known points instead of two. The big advantage of the Japanese satellite is that it permits measurement of both angle and distance. That way, the satellite's location (the value needed for determining position on earth) can be gauged using a single known point—a boon to mapmakers in poorly charted areas.

The satellite, which could be used by any country within 50° of the equator, is a 7-foot-diameter sphere comprising over 1400 prisms and 300 mirrors. To increase the brightness of the reflection, the mirrors are set at varying angles that approximate a sphere more than 50 feet across.

Patent automation pending

The U.S. Patent Office, which is busy loading its vast body of patent information onto computers, will make the database available to the public much sooner than originally planned. The new timetable calls for limited public testing in 1987 instead of sometime in the '90s, in order to guarantee that the database is suitable for public as well as internal use.

The public currently has access to U.S. patents on paper or microfiche at 60 regional patent search libraries. But with 4.3 million patents in 400 classes and 115,000 subclasses, a search can be frustrating and time-consuming. Not only will the new system make the process easier, it will also provide access to European and Japanese patents for the first time.

The Patent Office expects to have digital facsimiles of a test group of 400,000 U.S. and foreign patents loaded by the fall; at that point its staff will begin a trial use of the system. Then, in spring 1987, the public will be able to start testing the database at the Washington, D.C., patent library. Installation in the regional libraries is planned for 1990, by which time the system should contain all U.S. patents since 1970; French, German, British, and Swiss patents since 1977; and abstracts of Japanese patents since 1977.

Technology is the racer's edge

Ian M. Ross
President, AT&T Bell Laboratories

We have arrived at a time when certain realities about U.S. technological and economic leadership must be faced. Surely the day is past when we could boast "We're number one!"—with confidence and conviction—in virtually any field. If we do so these days, it is invariably while looking over our shoulder. We're still ahead in many ways, but we can hear the footsteps behind us getting louder.

Now, there are many who advise us not to panic. Bill Miller, vice-chairman of the board of Bristol-Myers, puts it this way: "Of course they're catching us. They're supposed to catch us. Adam Smith and David Ricardo warned us there would be days like this. It is the way economic adjustment works among nations." Then Mr. Miller goes on to explain why: as a nation gets successful and rich, it raises its wages and prices. And unless it can also increase its productivity, it loses business to poorer countries. This process runs its course when the newly rich tend to forget how they became rich and start consuming more than they invest in new means of productivity.

That process certainly seems to have been at work. But today the situation is far more complex. The new and highly integrated international economy makes it clear that economic growth need not be a zero-sum game. We are no longer in a race in which one nation wins while all others lose. Every participant, in effect, can be a winner. But "participant" is the key word: the goal is not to come in first in every race, but to be able to run. The U.S. must maintain its competitiveness, if not outright industrial and economic leadership, across the board.

The President's Commission on Industrial Competitiveness, on which I served last year, highlighted a number of factors that are key to our successful competition. It stressed the importance of capital resources and the need to stimulate productive investment. It focused on human resources, with major recommendations to increase cooperation between government, industry, and labor, and to improve education and training, including retraining of the workforce. And it emphasized the importance of improved international trade and investment policy. But while all of these are vital, the commission concluded that technology is where we have the greatest strength.

It's essential that we use our technological advantage because we are at a serious *dis*advantage when it comes to basic labor rates. In Japan and Korea, for example, average hourly labor costs are $6.48 and $1.30, respectively, while in the U.S. they are $12.26. Obviously we're not going to ask our skilled people to work for those kinds of wages. So if we want to compete, we have to use every possible technological means to drive down the labor content in our products.

> *The goal for American industry is not to come in first in every race, but to be able to run.*

Critical to technological strength is a commitment to R&D. Our total national investment in R&D this year will reach some $122 billion—representing about 2.9% of the GNP, the highest level since the mid-1960s. But while total amount may be important, where and how this money is spent is even more important. And perhaps most vital of all is spending it in ways that create an R&D synergism, one in which all sectors benefit and reinforce each other's strengths. We must have a greater flow and feedback of information between industry, government, and the universities. We need more of a systems approach.

I think we have begun to move in that direction. Examples can be found in the new industry–university cooperative efforts, the new National Science Foundation programs that aim to culminate in industry-supported engineering research centers, and the efforts to make more of the work of the federal laboratories directly useful to industry. We must continue to expand such cooperation in order to take full advantage of our technological resources. And we can do this without sacrificing the inventiveness and drive, both individual and corporate, that is so characteristic of American society.

Interdependency and synergy are critical not only in how we develop technology, but in the products themselves. We are moving rapidly into a systems world, one in which we develop products and their services to work together with other products and *their* services. We are learning this in almost every human endeavor. In my own field of information management, for example, we are finding that standalone products today have a short existence. The individual computer—one not able to network—is proving to be a prime example. This and other facts of life in AT&T's business have encouraged us to devote more attention than ever to systems engineering, operations research, and network architecture.

An important objective here is to provide flexibility. A major benefit

from software systems is that they allow us to customize products and services to individual needs and changing conditions. We can reduce early obsolescence and protect people's investments in costly technologies. Such measures will increase the confidence of customers and expand market opportunities for American industry. R&D must move us in this direction.

Another important aspect of R&D—one that we have seen growing throughout U.S. industry, but that needs to grow a lot more—is the focus on process and manufacturing. A key finding of our President's Commission on Industrial Competitiveness was that companies have generally failed to move new products from the design stage through manufacturing and into markets in a timely and efficient way. Both the quality and cost of U.S. products have been affected by this failure. And market opportunities have been missed because of many firms' slowness and ineptness in translating research results and new technologies into marketable products.

One of our problems has been that, although industry employs about 15% of the nation's scientists and 50% of its engineers, only a small number of them are involved in manufacturing R&D. We simply have not trained many people in this field.

At the same time, we have too few engineers in management—and too few managers who, even if not professional engineers, have enough understanding of the technical side of their business and its long-range needs. Training in business schools leans heavily toward financial and marketing needs, and invariably toward short-term successes. Meanwhile, our Japanese competitors, and others, have shown us the importance of longer-term strategic thinking.

But there are people who suggest a very different approach. If manufacturing, particularly of basic industrial products, can be done so well and cheaply abroad, they say, why not abandon those industries and concentrate only on the very high tech and service businesses with which we seem to be having more success?

It's essential to recognize, however, that manufacturing still produces 85% of this country's wealth. Moreover, competitiveness in services depends largely on a strong manufacturing sector, which invigorates GNP growth and creates jobs of all kinds. If the U.S. loses competitiveness in manufactured goods, it risks losing its position in services as well.

So we must temper our enthusiasm for becoming a service economy. We should recognize the ultimate danger of being a nation of shopkeepers selling the goods of other countries, or franchisers setting up fast-food stands in foreign cities, or even bankers handling the money and financial transactions of others. These things can be done, and we will no doubt continue doing them. But we should never believe that they can replace our industrial economy.

Nor should we write off the basic industries—many of which, some observers point out, are moving overseas anyway—and cast a vote for the high tech industries exclusively. There are good reasons to maintain a balanced industrial mix at home. One of these is the synergy between industries. The auto industry, for example, is this country's largest user of computers and industrial robots. Also, as we add more electronics to vehicles and the plants making them, we begin to convert the automobile and factories into higher technologies.

The same holds true in other fields—from steel to apparel to agriculture. The right R&D can transform a low or mid-range technology into one that, while not necessarily high technology in the usual sense, has all the "value added" to place it in a highly marketable category.

Consider how biotechnology is changing agriculture and the production of feedstock chemicals, not to mention its potential in medicine. Consider the materials revolution taking place today—in advanced ceramics, for example. Consider the influence of microelectronics on almost any imaginable field.

My point here is that high technology has an elevating effect. And we should use it to apply whatever kind of modern alchemy is necessary to enhance our other industries and services.

We simply cannot afford to be indifferent to the strategic and economic benefits of a diversified industrial base. And surely we must recognize that our advances in high technology spur whole new markets and industries that drive progress worldwide. □

BUSINESS STRATEGIES

3M:
PERSEVERING IN SPACE RESEARCH

When NASA began providing lab quarters for corporate research aboard the Space Shuttle, only one major U.S. corporation responded with enthusiasm: 3M of St. Paul, Minn. The first non-aerospace company to establish a space research lab, 3M has already conducted three experiments aboard the shuttle and remains committed to its program of materials research in microgravity despite the fleet's temporary grounding. 3M is currently negotiating with NASA for quarters on 73 additional shuttle flights as part of R&D programs ranging from electronics to healthcare.

Although the real returns on microgravity experimentation are long-range, "it has already given 3M a competitive advantage in understanding the properties of certain organic crystals," says James P. Samuels, VP of research at Shearson Lehman American Express. For example, Lester Krogh, 3M's VP of R&D, cites the company's success in growing a proprietary organic crystal during just seven days aboard the shuttle, despite years of thwarted efforts on the ground. The ability to grow crystals larger and more uniform than is possible in the earth's gravity is alluring to several of 3M's basic areas of business, including imaging, electronics, and healthcare. Another area of interest is studying thin films under microgravity, which may potentially lead to improved magnetic surfaces for a new generation of videotape.

Ironically, the company's initial involvement with the shuttle program was motivated more by hopes of landing government contracts than by potential R&D benefits, says Gerry Kottong, director of 3M's Federal Systems. But the interest of 3M's engineering staff soon prompted senior management to take a more serious look at space research per se, Krogh recalls. In 1983, for example, the company staged a "NASA Day" as part of its routine business-development efforts. Much to management's surprise, almost 3000 engineers packed the auditorium to hear NASA officials speak.

When 3M's first space experiment (growing ultrapure urea crystals on the shuttle mission in November 1984) proved successful, the company decided to fund a research lab solely for Space Shuttle projects. Opened in January 1985, the lab ensures "continuity and accessibility to space," says Christopher J. Podsiadly, director of the company's Science Research Laboratory. And as an unexpected bonus, the space experiments have opened a whole new area of business: providing consulting services to companies undertaking space research. 3M is also leasing its shuttle equipment (some of which it is trying to patent) and will package shuttle payloads in preparation for launching.

3M's Lester Krogh holds apparatus used to mix chemical solutions in some of the company's crystal-growing experiments aboard the Space Shuttle.

All these activities have so far cost 3M a great deal more money than they've generated. Although the company claims that space research accounted for just a tiny fraction of the $510 million it spent for R&D in 1985 (when total sales were $7.8 billion), Krogh acknowledges that "space isn't cheap, and there are no guarantees." But he notes that the program is already paying off in unexpected ways: "Recruitment for graduating engineers has become much easier," says Krogh, especially from eastern schools like Harvard and MIT.

—Jeffrey K. Manber

Palladian Software:
A.I. MOVES INTO EXECUTIVE SUITES

Until recently, most commercially available artificial intelligence (AI) software consisted of "tools" and "shells" that skilled programmers could use to create their own expert systems—programs that emulate the reasoning processes of human specialists. But last March, two-year-old Palladian Software (Cambridge, Mass.) began selling one of the first complete expert systems to come onto the market, a $95,000 program called Financial Advisor designed to help executives make capital budgeting decisions.

The program contains knowledge gathered from more than 30 experts in finance, business strategy, manufacturing operations, and AI, as well as summaries of U.S. tax law, Securities and Exchange Commission rulings, and economics formulas. To use the program, a manager must first enter company data, such as corporate structure, net present value, depreciation method, and desired rate of return for the project under scrutiny. The program can then automatically make risk analyses and determine break-even points for varying sales volumes and pricing structures. It can also carry on a dialogue with the user, asking for additional information and even challenging his or her assumptions.

"You really don't need to know accounting to use it," says Michael Gilboy, manager of business planning for accounting firm Coopers & Lybrand

(Boston). With the help of the program, Gilboy says, he can turn over detailed analyses of cash flow and return on capital investments to his staff.

Financial Advisor was the brainchild of Philip Cooper, chairman and CEO, who in 1983 took a year off to study AI at MIT after selling the software company he had started. In 1984, he and John Karcanes, president (then VP of marketing and international operations at Cullinet Software), founded Palladian, raising $11 million from venture capital firms such as Venrock (New York) and Kleiner Perkins Caufield & Byers (San Francisco). The company spent $5 million to develop its program and, in addition to the financial experts it consulted, sought advice from 10 potential customers, including Coopers & Lybrand, Digital Equipment, Norton, Cabot Corp., McKinsey & Co., and Texas Instruments. In return for their assistance, these companies were able to test prototype versions of the software before it was available to the public.

But not every company is a potential customer. The program's high price makes it economical only for large companies—those with $300 million or more in annual sales, Karcanes estimates—that perform capital budget analyses frequently. In addition to the purchase price, Palladian plans to charge $3000 a year for a semiannual update service that will incorporate changes in tax law, accounting methods, and even inflation and interest rate forecasts. Another hefty expense is the estimated $30,000–$50,000 purchase price of the specialized AI workstations (from Symbolics or Texas Instruments) for which the program was designed. Karcanes believes Financial Advisor may eventually run on IBM's powerful new RT personal computer, but only if the machine's screen resolution is improved and several other expected modifications are made. In the meantime, the added cost of specialized hardware will probably further limit the market to large companies, predicts Harvey Newquist, an AI analyst for research firm DM Data (Scottsdale, Ariz.).

Despite its still-nascent sales record, Palladian already has additional products in the works and hopes to introduce an expert system called Operations Advisor later this year that will help factory managers determine manufacturing requirements. The firm currently has no direct competitors; the closest is another Cambridge start-up, Applied Expert Systems, which sells a program for personal financial planning. Nonetheless, Newquist believes that these companies are the harbingers of a significant new trend to "off-the-shelf expert systems."—***David Sylvester***

Solar Steam:
COOKING WITH GLASS

With oil prices plummeting and the era of tax breaks for renewable energy sources apparently over, tiny Solar Steam (Tacoma, Wash.) seems an unlikely survivor in today's pared-down solar energy field. But its aluminum and glass dish for concentrating sunlight to produce steam has already come closer to commercial production than many observers expected. A meager $750,000 in backing from private investors has forced the company to "think cheap," says founder Doug Wood, making the dish he designed less expensive to build than previous glass dishes.

Solar Steam's parabolic concentrator differs from trouble-prone earlier versions developed in the U.S., France, and the Soviet Union, in its use of an aluminum geodesic frame—an intrinsically sturdy structure of interlocking triangular struts—to support the dish's mirrored inner surface. Able to withstand the stresses of wind, gravity, and temperature change, this support keeps the dish's focal point from drifting off the boiler at its center and, in the worst possible case, burning a hole in itself. The reflecting surface, made from hundreds of triangular glass mirrors, tracks the sun as it moves across the sky, driven by a computer-controlled system (which can also turn the dish face-down on the ground in the event of high winds).

The company's first prototype, rated "competitive and commercially of value" by the National Bureau of Standards, was found to capture 79% of the thermal energy bathing the reflector area, in a battery of tests conducted by the Solar Energy Research Institute (Golden, Colo.). Wood claims that a new, larger version priced at $25,000 can produce steam efficiently enough in sunsoaked spots like Yuma, Ariz., to generate electricity at an installation cost of $1.50 per watt, only slightly higher than the $1.20-per-watt installation cost of small-scale hydroelectric equipment.

The company also hopes to find a market in supplying steam for industrial processes, in the belief that this represents the most efficient application of its technology. "But it's a rare industrial process that can use steam that goes on and off with the weather and quits completely when the sun goes down," observes Edward Blum, a solar energy analyst for Merrill Lynch in Washington, D.C. Possible solutions may be found in new heat storage technologies, such as techniques developed by researchers at the Sandia National Laboratory for temporary thermal-to-chemical energy conversion. But the additional costs, Blum argues, would probably make a system too expensive to compete with fossil fuels. This could restrict it to use as a supplementary energy source, except in remote locales where fuel shipping costs are higher.

Solar Steam also faces competition from other dish manufacturers. Start-up LaJet Energy (Warner Springs, Cal.) makes a dish that has a lightweight polymer reflecting surface, and aerospace giant McDonnell Douglas (St. Louis) makes a glass dish that is shallower than Solar Steam's. Although the company has come a long way on "really minimal financing," says Blum, to stay in the running it must tackle what he considers the far more difficult task of mass-producing dishes cheaply. Solar Steam itself estimates that it must raise more than $18 million—a substantial sum in today's depressed energy market—to build the 500-dish demonstration plant it hopes to complete by 1989 to produce heating and cooling for a college campus or another such institution.

Despite skeptics' doubts that such a large-scale project will ever come to pass, Wood remains confident that he can obtain backing from investors committed to solar energy. He believes the project may finally prove that solar energy can actually compete on this scale with fossil fuel. —***Brad Warren***

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- In Hawaii, you can call Tokyo, Singapore, Hong Kong and the U.S. mainland *all during the same business day.*
- Hawaii ranks 4th in the U.S. in percentage of college-educated individuals in the workforce.
- University of Hawaii electrical engineers ranked first and second in a national recruiting campaign conducted recently by Motorola.
- Of all college students studying Japanese in the U.S., one in three is at the University of Hawaii.

ARTIFICIAL INTELLIGENCE ENTERS THE MAINSTREAM

Computer users who have been waiting for products based on the much-touted technology of artificial intelligence (AI) have so far seen only a trickle of initial offerings. But AI, which has been confined largely to R&D laboratories, is finally poised to move forcefully from the development to the delivery stage. Propelling this transition will be the mainstream computer vendors, who view AI as a pervasive technology that can be merged with existing products to make them more powerful and easier to use—in effect, "smarter."

AI is fundamentally a software technology that can be adapted to run on any type of computer—whether micro, mini, or mainframe—in conjunction with most conventional software. The manufacturers of these computers have therefore become active in developing and disseminating AI technology, not only to garner a portion of what promises to be a multibillion-dollar business, but also to ensure that their users have access to its benefits.

The definition and value of the AI market will become increasingly difficult to gauge, because the technology will often be buried within more conventional products. For example, a credit authorization package could incorporate an AI module to handle marginal cases now referred to human operators for resolution. An electronic mail system might add a component that intelligently sorts messages by priority and content. Process control software could "understand" the nature and operation of the equipment it directs. And much software could exploit the power of speech recognition and natural-language interfaces to permit users to interact with the computer in ordinary spoken English.

by Dwight B. Davis

This integration is at odds with the common perception that AI is synonymous with special-purpose computers called LISP machines and with "expert system" software (which emulates the specialized knowledge and reasoning ability of human experts). LISP machines and expert systems have typically operated in a world of their own, and the field of AI has tended to be associated more with trying to produce "thinking" computers than with enhancing traditional applications.

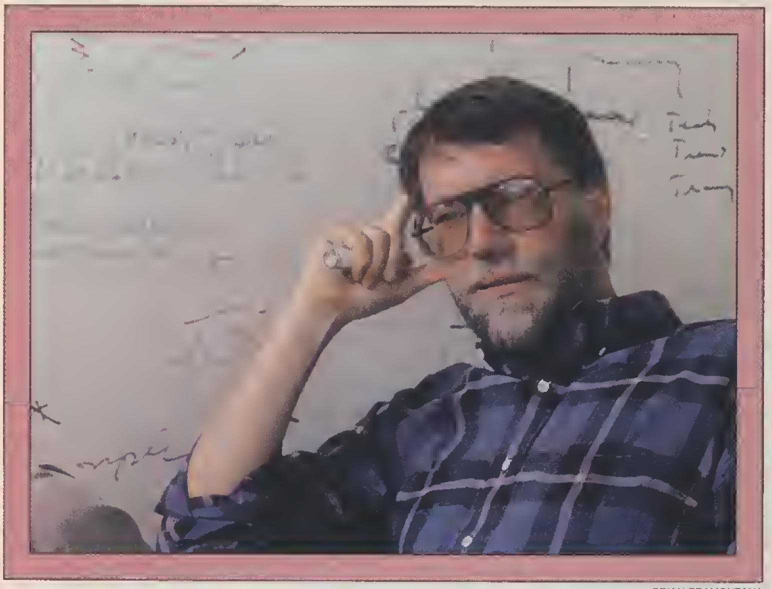
But developers' current focus on practical uses represents a bona fide metamorphosis from the early years of AI, says Richard P. Ten Dyke, assistant for business analysis, products, and technology at IBM's Information Systems & Storage Group (White Plains, N.Y.). Ten Dyke, who first explored AI at IBM in the early 1960s, notes that "instead of trying to recreate the human mind, the goal of AI has become much more focused on making computers more productive."

Computer vendors' role. To participate in the commercialization of AI, the major computer companies are pursuing several tacks: developing in-house AI projects to streamline their own operations and to gain experience with the technology; planning new generations of hardware products that run symbolic AI programs as well as conventional numeric applications; remarketing AI-based software programs developed by third parties; and, in some cases, planning AI software of their own.

The most renowned of the in-house projects is an expert system called XCON (short for "expert configurer"), developed jointly by researchers at Carnegie-Mellon University and Digital Equipment Corp. (Maynard, Mass.). DEC's VAX computer line consists of hundreds of components that can be configured in thousands of ways; XCON suggests the best configuration on the basis of each customer's requirements. By reducing the number of false orders for unneeded components, "XCON is saving us roughly $18–20 million per year in manufacturing costs," says Joel Magid, senior product manager of DEC's AI Technology Group.

The success of in-house AI development activities has often helped convince computer vendors' top management that AI will become an important part of the products they market to the outside world. Xerox's Palo Alto Research Center (PARC)—for years a leading AI research institution—has kept the company abreast of the technology and provided the basis of Xerox's LISP machine product line. But AI did not become one of Xerox's main strategic goals until in-house projects began to streamline the company's own internal operations and to assist in product development.

In one case, the use of AI support software—soon to be marketed as a product called Trillium—enabled Xerox designers to efficiently collaborate on the development of simple interfaces for a complex line of copiers. Thanks to that project and others, "we find that the company at large has a better understanding of what the AI game is all about, and is becoming more interested in aggressively supporting it," says John Seely Brown, manager of PARC's Intelligent Systems Laboratory.



BRIAN TRAMONTANA

Major computer vendors are helping to push "smart" systems out of the lab and into the market-place

Similarly, in-house AI activities at IBM helped convince the company's management to form an AI Projects Office about a year ago to coordinate the development of commercial AI products. IBM's primary AI focus will be on its traditional market: the management information systems community working with the company's mainframe computers. Its first products have been expert system development packages for mainframes that run the VM or MVS operating systems. Outside software suppliers, on the other hand, are targeting IBM's new PC/RT engineering workstation as the vehicle of choice for their AI products. In any case, stresses Ten Dyke, the AI products must mesh smoothly with existing software and databases. "Most of the people using AI applications in the commercial environment are going to want access to corporate data that already exist on their current systems," he says. "It would be silly to have to reintroduce those data into a stand-alone system to perform AI operations."

Customers of computer manufacturers that use AI internally may realize benefits beyond those of AI products alone. If the vendor succeeds in using AI to improve the efficiency of its operations, it may reduce the manufacturing time and cost of its products. In addition, such vendors will be able to pass their AI experience on to customers. Indeed, some observers believe the main role for hardware manufacturers in popularizing AI may be as service providers that introduce AI to their user bases and help them assimilate the technology. "It will take the computer companies to educate the world about artificial intelligence; it won't take them to develop the technology," says Alexander D. Jacobson, president of Inference (Los Angeles), the independent supplier of a leading expert system development tool.

The LISP environment. In-house AI expertise at mainstream computer firms may have another important benefit: helping the computer manufacturers learn how to build machines that better run AI programs in conjunction with conventional software. It's no mystery how to build hardware dedicated to AI software alone; several companies have such computers on the market already. But they were all built specifically to run LISP—the programming language that has become the lingua franca of AI scientists in the United States. They tend to be expensive and special-purpose.

The four symbolic processing vendors—Symbolics (Cambridge, Mass.), LISP Machine Inc. (Andover, Mass.), Xerox, and Texas Instruments (Dallas)—are currently trying to broaden their products' usefulness in two ways. They are making their equipment compatible with industry standards such as the UNIX operating system and the IBM personal computing and networking architectures, and they are introducing new low-cost models of their symbolic processors to serve as delivery vehicles for products developed on their more powerful machines.

Xerox was the first to introduce inexpensive LISP machines, and still has the low end of the market much to itself. Its 1185 workstation costs as little as $9995 and can interface to the IBM PC. Market leader Symbolics has jumped into the delivery game as well, albeit with a higher-priced product. In quantities of

Xerox's Brown: "Along with streamlining our own operations, we hope to use AI to add intelligence to office automation."

10, its new 3610AE machine costs $39,600—relatively expensive, but nevertheless a considerable drop from the $100,000–$200,000 price of its top-of-the-line 3670 family of development products.

The conventional computer vendors have been introducing LISP compilers on their machines as a first step toward being able to support AI programs. This step has been simplified by the establishment of a standard version of LISP called Common LISP (many "dialects" of LISP had evolved over the years) and by the formation of companies such as Lucid (Palo Alto, Cal.), Gold Hill Computers (Cambridge), and Franz (Alameda, Cal.), which have written LISP compilers for most of the popular computers. One of the last holdouts is Xerox, but it plans to support Common LISP on its machines soon. IBM also has yet to introduce such a compiler, but Ten Dyke says the company believes that "Common LISP is a requirement for the future."

By running LISP compilers, the general-purpose computers have begun to compete with LISP machines. "The fallacy is that a conventional computer system cannot run LISP as well as a LISP machine does," says Nelson Hazeltine, director of systems environment architecture and advanced software technologies at NCR (Dayton, Ohio). "We've found that there's no performance difference." The LISP machine manufacturers contest such claims, however, asserting that benchmark tests, which measure a computer's speed in running a LISP program, fail to

measure the full value of their products. "LISP machines give you a total LISP environment, containing all the features that improve your productivity and your ability to generate code reliably and quickly," says Wally Rhines, president of TI's Data Systems Group. "Those qualities are hard to measure in standard benchmarks."

Increasingly, however, conventional computers do have access to such LISP environments. Several years ago, a few start-up companies began introducing software designed specifically for the construction of expert systems, which by then had become the focus of most AI activity. These software packages, known collectively as expert system "tool kits" or "shells," were written in LISP and initially designed to run on LISP machines. But in recognition of market opportunities, the tool kit vendors have more recently been rewriting their products to run with the LISP compilers on conventional machines. Some speed is lost—LISP machine implementations are generally more efficient—but a broad new spectrum of users is gained.

Many in the industry believe the widespread dissemination of powerful programming environments will be one of AI's most lasting legacies. At large corporations, most software is developed or customized in-house, and even with programming tools such as fourth-generation languages and COBOL generators (HIGH TECHNOLOGY, April 1986, p. 38), the job can be long and arduous. "By the time the software is developed, the user's requirements have often changed," says Inference's Jacobson.

The AI programming environments speed this process, permitting the rapid prototyping of new software systems. And the development benefits are not limited to AI applications. "You can use this AI programming methodology to tackle effectively a broad class of problems, producing solutions that are not in their own right classified as intelligent," says Brown at Xerox.

To further expand the audience for their products, and to speed up running time, the leading tool kit vendors are introducing new versions of their products written in C, the language of the Unix operating system. C is not really a symbolic processing language, but with certain extensions it can be used to write AI programs that perform the same functions as their LISP counterparts. "The optimal solution," says Larry K. Geisel, president of the tool kit vendor Carnegie Group, "may be to develop AI applications in LISP and port them to C for execution."

Hybrid systems. Even as developers move to fast-running C as a language for AI delivery, the pressure remains great to develop more powerful general-purpose computers capable of blending AI smoothly into their software repertoire. "You want machines that can do symbolic computing, but not at the expense of conventional computing," says Ira Goldstein, director of the Distributed Computing Center at Hewlett-Packard Laboratories (Palo Alto).

Goldstein says that HP's forthcoming Spectrum line is a step in the right direction. The new computers will have a large address space—a key requirement for knowledge-intensive AI programs—as well as a large number of storage registers, which can hold functions commonly used by the LISP language. Perhaps most important, the Spectrum computers are designed to support coprocessors of different types. Many observers believe that the hybrid machine of the future will have both general-purpose and LISP microprocessors working together to run (respectively) the numeric and symbolic portions of mixed applications.

Texas Instruments is a leading advocate of supporting a general-purpose microprocessor with a LISP chip—not surprising, since the company expects to produce the industry's first such chip this fall. The chip, which will contain approximately 60% of the circuits found in TI's full-blown Explorer LISP machine, is being developed as part of a $6 million DARPA contract to produce a "Compact LISP Machine" no larger than a shoebox. Once it has met its contractual obligations, TI can use the LISP chip in whatever way it wishes, bundling it within its own computers or selling it on the open market. "We might keep it internal for a while; we might also sell it to the workstation vendors," says George Heilmeier, senior VP and chief technical officer.

The vendors of engineering workstations are a likely market for such a chip because two of the leading vendors—Apollo Computer (Cambridge, Mass.) and Sun Microsystems (Mountain View, Cal.)—have already signed marketing and development agreements with Texas Instruments in order to link their products to TI's Explorer machines. Under these agreements, the workstation vendors will work with TI to integrate Explorers into the workstation networks, where they will serve as development systems and as "knowledge servers," running AI applications that users can access over the networks. In these initial links between symbolic and numeric processing, the "hybrid" environment is being produced by coupling full-blown computers of each type via a network, not through the use of coprocessor chips within a single machine. "We're looking at AI as a systems approach, rather than as a solution-in-a-box approach," says Paul Armstrong, project manager of AI and data management at Apollo.

R. HAMILTON SMITH

Larry Walker, director of Sperry's Knowledge Systems Center, views AI as both a mandatory technology and an unparalleled opportunity.

Armstrong agrees, however, that LISP chips might eventually work their way into workstations. Already, workstations are emerging in many circles as the preferred type of AI computer. They cost considerably less than most LISP machines, incorporate the same kind of powerful graphics displays, and can provide respectable performance, thanks to the power of general-purpose microprocessors such as the Motorola 68020 and the Intel 80386. The entry of IBM, with its PC/RT, and DEC, with its MicroVAX II, into the workstation market has attracted even more interest from the AI community. Most expert system tool kit vendors, for example, have already ported their products to these machines or plan to do so soon. DEC even markets a version of its MicroVAX II bundled with Common LISP and a graphics interface as the "AI VAXstation."

A sampling of AI activity at computer companies

Apollo

AI products: Common LISP; TI's Explorer LISP machines with links to Apollo's Domain workstations; various expert system tool kits.
Organization: Created an AI project manager position a year and a half ago. The company's internal AI work consists primarily of ensuring that third-party AI products are compatible with its own.
Comments: Positioning its Domain workstations as AI delivery vehicles and medium-power development machines; expects the Explorer line to handle the development and running of extremely complex software. Considers AI a critical technology, as important as graphics.

Data General

AI products: Common LISP; negotiating marketing agreements with expert system tool kit vendors.
Organization: Created an AI Business Unit, preparing its first strategic recommendations. Has several internal AI projects under way.
Comments: Expects the AI terminals of choice to be IBM PC/ATs and compatibles in commercial markets, engineering workstations in technical markets. Plans to be "pragmatic," providing its customers with the AI they want, regardless of source.

Digital Equipment

AI products: Common LISP, OPS-5, and PROLOG languages; third-party expert system tool kits; AI VAXstation.
Organization: Has AI technical development and marketing groups. More than 300 employees are working on 40-plus internal AI projects. Member of the Microelectronics and Computer Technology Corp. (MCC) consortium.
Comments: Has a long AI history, including close collaboration with leading universities. Expects to develop its own AI software for horizontal applications such as office automation. Plans to leverage its experience to serve as an AI consultant to its customers.

Hewlett-Packard

AI products: Common LISP on HP 9000 workstations; third-party expert system tool kits.
Organization: HP Labs focuses on AI research with a 3–7-year leadtime; the R&D labs within each operating division work on projects with faster payoffs. Developing several AI packages for internal use.
Comments: Will rely on third-party suppliers for AI, except in areas such as instrumentation, where the company may develop its own AI products. Believes the software productivity benefits of AI will be extremely important throughout the company.

IBM

AI products: Expert System Environment/MVS and ESE/VM tool kit products for its mainframes; remarkets the Intellect natural-language processing interface.
Organization: Established AI Project Office about a year ago. Has various AI R&D projects scattered throughout the company. Its Yorktown research labs have conducted AI studies for more than 20 years.
Comments: Considers AI to be one of several important technologies, but not a revolutionary one. Expects AI to find application across its product lines, which is why the company formed the corporate-level Projects Office rather than an independent business unit (as was done for the PC).

NCR

AI products: Common LISP; plans to resell third-party expert system tool kits.
Organization: AI falls under the Advanced Software Technologies group, which acts as an information clearinghouse and helps fund AI research within various company business units. Has over 20 in-house projects under way. Member of MCC.
Comments: Believes both AI development and delivery should be done on general-purpose computers to achieve the best integration of the technology. Aiming to make products useful to software engineers.

Prime

AI products: Plans Common LISP release; evaluating third-party expert system tool kits.
Organization: No central AI group. Research is dispersed throughout the company. Funds some AI research at two British universities.
Comments: Doesn't plan to pioneer AI; rather, will work with outside suppliers to integrate the technology with its products. A key area of development will be knowledge bases for CAD/CAM systems.

Sperry

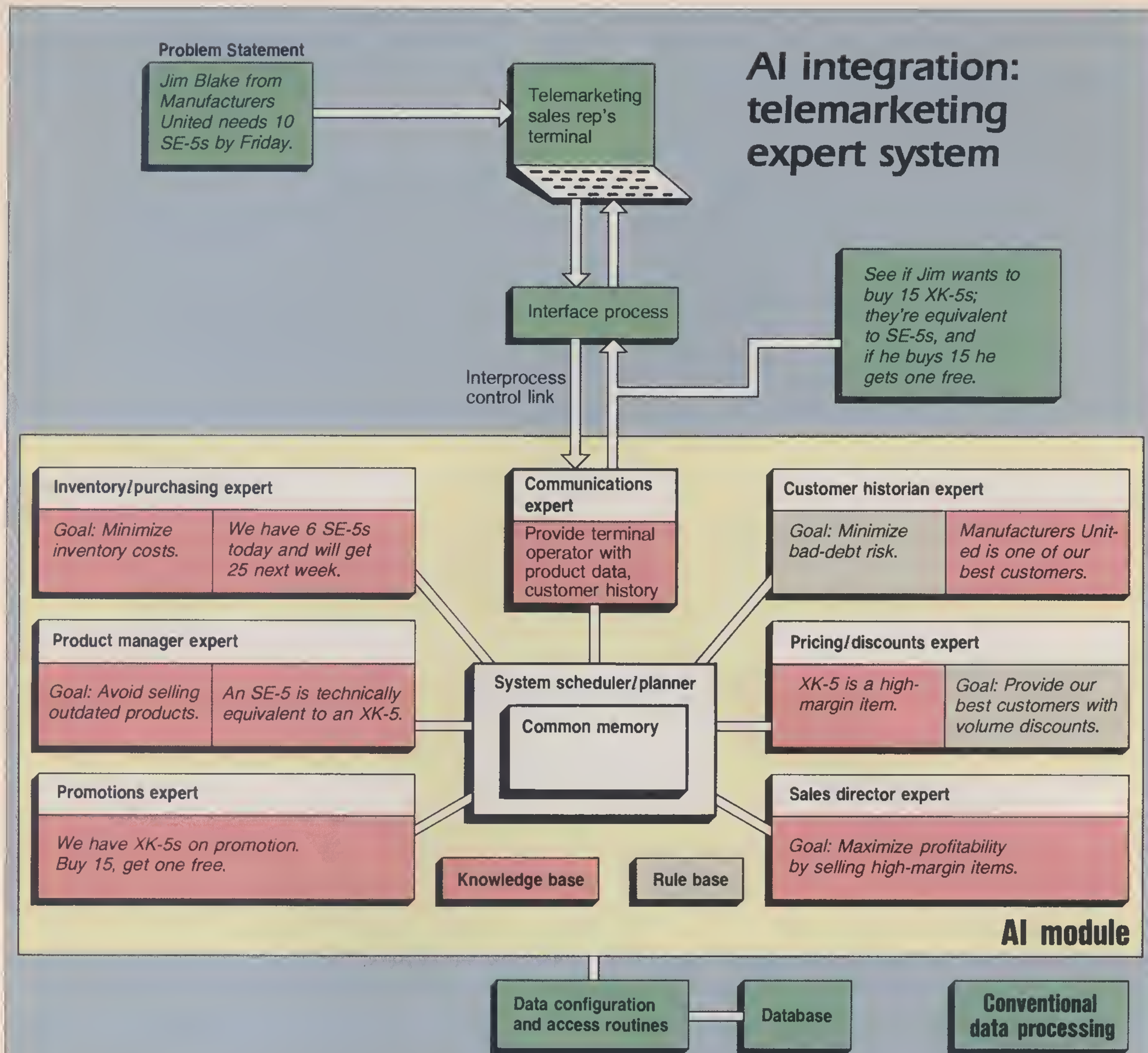
AI products: Sells a bundled AI development package consisting of TI's Explorer LISP machines and IntelliCorp's KEE expert system tool kit.
Organization: AI under the control of the 20-person Knowledge Systems Center. More than 200 people working on 50-plus internal projects. Spent about $30 million on AI R&D last year. Member of MCC.
Comments: Views AI as strategic technology of the 1990s, and has embraced it as the best way to distinguish itself from competitors. Plans to develop its own horizontal application products and to serve as a consultant to customers.

Texas Instruments

AI products: Explorer LISP machines; Personal Consultant Plus expert system tool kit; remarkets third-party tool kits; developing LISP chip.
Organization: AI R&D has been conducted at its Central Research Labs since 1978. Most products marketed through the Data Systems Group. Developing and operating numerous internal AI systems.
Comments: Hopes to use AI to leverage itself into the forefront of mini/microcomputer vendors. Considers AI second only to VLSI in strategic importance. Has worked harder than any other computer company to identify itself with the technology; stages nationwide AI satellite symposia.

Xerox

AI products: The 1100 series of LISP machines running Interlisp D; Common LISP due soon; NoteCards-D, an "idea-processing" software package.
Organization: Advanced R&D performed at its Palo Alto Research Center, including the study of both human and artificial intelligence. Working to ensure close cooperation with the company's AI systems business unit.
Comments: Performing what is probably the most theoretical AI research among all the computer companies. Focusing its efforts on document processing, including software that facilitates the "social intelligence" involved in collaborations. Plans to reverse the "PARC syndrome," under which some innovations have never reached the market.



The TOLAS-Telestream system, developed by Carnegie Group for CSI-Transcomm (Pittsburgh), shows how AI components can be integrated with an existing data processing application. The AI module contains six expert systems that perform functions previously handled by human specialists, plus a communications expert to manage the exchange of information. When a customer calls in an order, it enters the system as a "problem statement." Each expert system, under the arbitration of a system scheduler/planner, tries to solve the problem with its own special knowledge. Most have goals, which are based on rules from the rule base, knowledge from the knowledge base, and facts stored in the conventional database. For example, realizing the goal of not selling to credit-risk customers requires that the caller's rating be determined, on the basis of conventional data such as annual sales. Once the AI module has arrived at a solution that meets both the customer's needs and the vendor's goals, the solution is sent to the terminal screen to be relayed to the customer.

The growing power of the general-purpose microcomputers embedded in such workstations has some manufacturers questioning the need for specialized LISP hardware. If conventional chips get fast enough, the argument goes, they will be able to adequately run both numeric and symbolic processing tasks at a price far below that of special-purpose devices. Digital Equipment's Magid points out that the MicroVAX II, which costs less than $50,000, is roughly the same speed as a VAX-11/780, which sold for more than $300,000 in 1978. "I think in a short period of time you will see the MicroVAX as a $10,000-$15,000 machine," he says. "There's a point at which the LISP machine argument holds, and a point at which it breaks."

But some maintain that the argument will hold indefinitely—that there will always be a role for LISP machines in developing and running large and complex AI programs. "DEC is saying that its standard microprocessors are getting to be powerful enough that you can do significant AI work on them. No one would quarrel with that," says Xerox's Brown. "But you might still get another fivefold improvement by going to specialized architectures." Such an improvement could be critical, says Inference's Jacobson, because "artificial intelligence is an extremely 'cycle-hungry' [i.e., power-demanding] technology. There is never going to be a chip powerful enough that you can afford to throw away cycles."

CAROL LEE

RON KIMBALL

***HP's Goldstein:** "Where we have special needs that aren't ideally served by third-party vendors, we may choose to build our own AI products."*

***DEC's Magid:** "AI alone won't solve everybody's problems, but it will be integrated with other technologies to produce useful new products."*

LISP machine evolution

LISP (short for "list programming") became popular in the AI community because it was designed to process—and form associations between—symbols such as words. In this it is different from most other programming languages, which are suited to performing primarily numeric calculations. Most languages can be used to do some sort of symbolic processing, but LISP and PROLOG (short for "programming in logic") are far more efficient at this task than numeric-oriented languages such as Cobol.

Even with a symbolic programming language, however, AI researchers were pushing the limits of software and hardware technology from the beginning. AI programs are notorious for requiring huge amounts of memory and machine cycles, especially during development. To speed the development process, researchers gradually built up an "environment" of programming tools such as program debuggers and sophisticated graphics interfaces. The resulting LISP environment far surpassed those of the numeric-type programming languages.

Still, software tools on their own weren't enough of a solution for AI development, and in the mid-1970s projects were independently begun at MIT and Xerox's Palo Alto Research Center to build hardware specifically matched to LISP and its development environment. The MIT project—funded by grants from the Defense Advanced Research Projects Agency (DARPA)—resulted in a machine called CADR (after a LISP primitive function), which eventually formed the basis of the first commercial LISP machines, introduced by Symbolics and LMI in the early 1980s. TI also sells a LISP machine whose roots can be traced to the CADR. Xerox, pursuing its own design program, also introduced its first LISP machine in the early 1980s.

The availability of commercial computers designed specifically to exploit the LISP development environment brought artificial intelligence a step closer to the consumer market, but the early machines were expensive and targeted only toward laboratory researchers. New, less expensive models have been introduced, however, in an attempt by the LISP machine vendors to garner a piece of the lucrative end-user delivery market.

Software skepticism. No one doubts that the major computer vendors will play an important role in disseminating AI products and building suitable hardware to run hybrid applications. But when vendors such as TI and DEC discuss plans to develop commercial AI software, rather than simply resell the products of third parties, skeptics begin to materialize. "The hardware companies have never done well in software," says Jacobson, who thinks that situation is unlikely to change. Even "system software" such as operating systems, language compilers, and programming tools is developed largely by outside parties, notes Larry R. Harris, president of Artificial Intelligence Corp. (Waltham, Mass.).

Some of the major computer firms actually concur with these opinions. "You shouldn't expect to see fundamental AI research coming out of Prime," says Richard H. Mott, director of AI within the company's CAD/CAM and Workstations Group (Natick, Mass.). "We will strike suitable relationships with external AI companies, so there will be no need for us to recreate products." Similarly, Data General (Westboro, Mass.) is formulating agreements to remarket various expert system tool kits on its computers, says Peter Jessel, director of the company's AI Business Unit. "It doesn't take a hell of a lot to be a major player in the game, other than the commitment to sign the appropriate third-party vendors and to start installing their AI products," he says. In

Expert systems and AI hardware reach commercial markets

As mainstream computer vendors begin to enter the artificial intelligence (AI) arena, the technology's pioneers—relatively small companies, in general—are following a number of strategies to survive and grow. In essence, they are taking steps to make products more appealing to traditional computer users in a wide variety of business environments.

AI products fall into several market segments, including specialized hardware, programming languages, expert systems, natural-language software, voice recognition, and artificial vision systems. These segments should make up a total market of $1 billion this year, rising to $4.2 billion in 1990, according to DM Data (Scottsdale, Ariz.), a market research firm that follows the industry. Two of the most active segments are AI hardware and expert systems, which account for 49% and 13% of the current market.

Symbolics (Concord, Mass.) dominates the production of symbolic processing computers—hardware optimized for creating AI software based on the LISP programming language. With 58% of the market for such dedicated computers, Symbolics is trailed by LISP Machine Inc. (Andover, Mass.), Texas Instruments (Dallas), and Xerox (Pasadena, Cal.), which share another 34% of the LISP machine market almost equally. LISP machines themselves, however, constitute only $200 million of the current $510 million market for all computers used in AI processing. The rest of this market consists of general-purpose machines that run AI software written in languages more widely used than LISP.

To expand their commercial opportunities, these first-generation AI companies have been adapting their products to conventional computing systems and traditional end users. LISP machine manufacturers, for instance, are developing networking links between symbolic processing computers and standard minis and mainframes. They are also offering low-cost machines that can compete with relatively inexpensive engineering workstations for running AI software.

At the same time, these firms are opening up niches for their products in specialized fields outside AI. For example, Symbolics is developing marketing alliances with companies that will package Symbolics' LISP machines with software that may or may not be related to AI. The first such company to sign up has been Icad (Woburn, Mass.), which produces modeling software used by contract engineering companies for the custom design of large industrial machines; Icad considers a LISP operating environment the most appropriate for its software. "By making such use of applications-oriented software firms, Symbolics can move its product out of the initial round of hard-core AI customers," says Carol Weiszmann, editor of *AI Markets* (Natick, Mass.).

> ***"To reach mainstream markets, AI vendors must make their products more accessible to end users and relevant to the computing environments in which they operate."***
>
> ***Carol Weiszmann, Editor AI Markets***

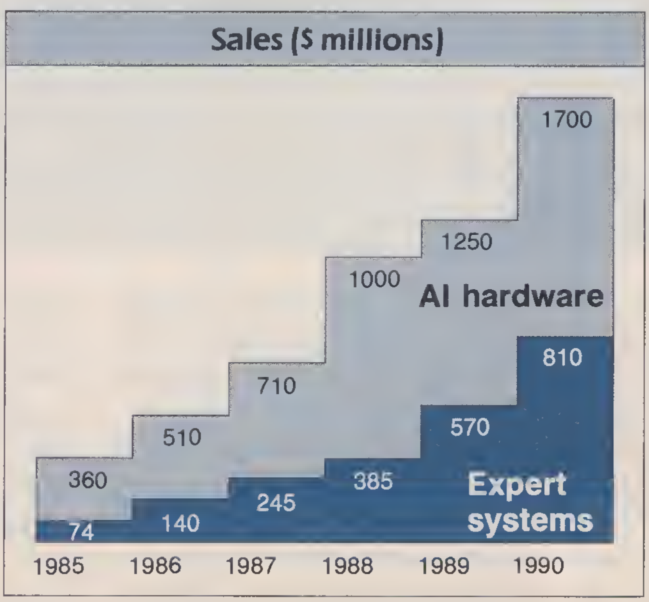
Expert systems—programs that codify and manipulate the knowledge of human specialists—have traditionally been developed in-house, and from the ground up, by large companies for their own use. But expert system development can be simplified and speeded up by a wider range of users with the aid of "shell" or "tool kit" systems, commercially available products that contain generalized rules of logic and support software.

The leading tool kit vendors are IntelliCorp (Mountain View, Cal.), Teknowledge (Palo Alto, Cal.), Carnegie Group (Pittsburgh), and Inference (Los Angeles); together, these firms control over two-thirds of the $70 million 1986 market for commercial tool kits. An additional $70 million is earned by companies performing government expert system contract work or offering custom services.

"Most AI development systems available are oriented to the several thousand computer scientists who have worked in LISP environments," says Larry K. Geisel, president of Carnegie. He believes that tool kits must be offered on two other levels to reach a wider market. One level consists of novice AI programmers for whom existing or somewhat redesigned tool kit software written in the C language is more appropriate. C is less powerful but more flexible and familiar than LISP, and can be used on Unix-based workstations, which run C faster than LISP.

Geisel says that the second level comprises the much larger group of conventional programmers who have had little or no exposure to AI. To tap this market, Carnegie is working on C-based shells embedded with inference strategies (such as when to use forward-chain reasoning) and other design considerations that AI programmers would prefer to handle themselves. Such shells also contain some of the knowledge needed to solve particular classes of problems, such as simulations and product configurations. "With this kind of product," says Geisel, "companies won't have to retrain whole cadres of programmers to use AI."

—Dennis Livingston



Source: *AI Trends '86*, DM Data Inc.

Japanese firms pursue their own AI agenda

Much of the current artificial intelligence activity at U.S. computer manufacturers can be directly linked to Japan's 1982 announcement of its Fifth Generation project. The 10-year project, directed by the Institute for New Generation Computer Technology (ICOT), has set ambitious goals to develop AI software and related hardware. These goals include the creation of knowledge bases that hold up to 100 billion bytes of information and 20,000 expert system rules.

ICOT is organized under the powerful Ministry of International Trade and Industry (MITI) and supported by eight Japanese companies—including Fujitsu, NEC, and Hitachi, the three largest computer manufacturers. It exercises an important influence on the direction of Japan's AI research and has provoked responses throughout the computer community in the U.S., most visibly in the formation of the Microelectronics and Computer Technology consortium (Austin, Tex.). Nevertheless, ICOT by no means controls all the Japanese AI research. Some corporate R&D projects in Japan are actually pursuing alternatives to the Fifth Generation's path. For example, while ICOT has embraced PROLOG as the foundation language for its AI efforts, many researchers at NEC are working with LISP.

In general, however, Japanese firms support ICOT without being overly reliant upon it. "We cooperate with ICOT, and if their work proves feasible we will acquire the technology," says Makoto Amamiua, director of information sciences at the NTT Research Laboratories. "But we don't give ICOT access to our proprietary research."

If any one theme is held in common by both ICOT and the computer companies, it is that AI software should be developed in close coordination with new types of supporting hardware. This pairing goes beyond the matching of LISP with LISP machines in the U.S., although there are some similarities. The Japanese are trying to build hardware "inference engines" to speed the operation of their AI software, as well as database management machines to handle huge storehouses of facts.

In each case, researchers are developing parallel computers—in which many processors tackle a problem simultaneously—to provide performance several orders of magnitude beyond today's machines. "Parallel architectures have been shown to be very good for logic-programming languages such as PROLOG," says Yoshihisa Ogawa, chief of ICOT's Research Planning Section. When PROLOG searches for information, it follows several branches of a treelike hierarchy at the same time; a parallel computer could closely match this software mechanism.

Each of the Japanese computer companies claims to be working on the whole software/hardware milieu. Mitsubishi Electric, for example, is investigating highly parallel architectures for superspeed machines, and is bringing to market a sequential inference machine. The latter, similar in concept to a LISP machine, was developed in conjunction with ICOT to run PROLOG. The company's software efforts, meanwhile, include projects in intelligent database management systems, natural-language processing—including Japanese/English translation systems—and knowledge representation studies.

Through their software projects, the companies intend to disprove the common belief that the Japanese, while good engineers and hardware architects, are poor software developers. For example, Computer Service Corp. has formed an entire branch, the CSK Research Institute (CRI), to perform basic AI research and to develop and market AI software products. CRI has also shown a willingness to market existing products; one of its first was the Knowledge Engineering Environment expert system tool kit from IntelliCorp (Mountain View, Cal.).

"Over 300 companies are working with us in one capacity or another," says Koji Yada, president of CRI, "which shows how many Japanese firms are interested in artificial intelligence." CRI is developing software for existing computers, such as the Digital Equipment VAX line, as well as for the computers coming from the ICOT project. CRI may eventually offer some packaged software, but off-the-shelf applications "are not the method used in Japan," says Yada. "We will work jointly with our customers to develop custom artificial intelligence packages."

the end, Jessel believes, customers will commit to companies like Data General, DEC, and IBM not so much because of their AI expertise as because they represent full-service vendors that have proved themselves capable of meeting their customers' needs.

To help the computer companies satisfy customers, independent firms known as value-added resellers (VARs) have traditionally bridged the gap between the manufacturers' products and the users' application requirements. But VARs specializing in AI have been slow to develop. "Vendors like TI and DEC really have to cultivate those firms in order to spread AI technology," says Kenneth R. Soneclar, VP of research at market research firm New Science Associates (South Norwalk, Conn.).

Still, mainstream computer companies are under increasing pressure to diversify into application software. Profit margins have dropped as computers have become more like commodities, says Susan Messenheimer, president of AIM Publications (Natick, Mass.), which publishes the *Artificial Intelligence Markets* newsletter. "The large companies are not just going to hand over the very lucrative AI software market to anyone else," she says.

Sperry, for example, is spending $30 million on AI R&D a year and has more than 200 people working on over 50 internal projects. It is remarketing an AI development package consisting of TI's Explorer LISP machine and IntelliCorp's KEE expert system tool kit, but it plans to produce its own AI-based horizontal application products as well.

Texas Instruments has produced expert system development tools, and may do packaged applications in the future, according to Heilmeier. But the most important AI software area that TI plans to exploit is what he calls "late-binding" applications, "in which most of the work is generic to several different applications, and there's customization at the final step that makes them unique to a specific customer," analogous to gate arrays in the integrated circuit domain.

Regardless of whether the computer companies actually make modifiable software products, such packages are considered crucial. This is especially true for large corporate customers, which often rely heavily on their own data processing departments or on third-party software houses to tailor applications to their employees' needs. In this customization process it is extremely important to get both end users and computer companies involved. "If you fail to do this," says IBM's Ten Dyke, "you run a very high risk of offering them something that does not solve their problems." □

Dwight B. Davis, a senior editor of HIGH TECHNOLOGY, *is coauthor of* Artificial Intelligence Enters the Marketplace *(Bantam Books, 1986).*

For further information see **RESOURCES**, *p. 68.*


PAIR?
PARE?
PEAR?

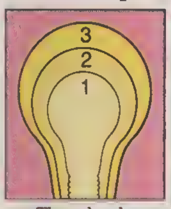
Would you like to know how computers can tell the difference between a pair in a poker game and a pear on a plate?

How they can understand a variety of speakers with a diverse variety of accents—and reply in pear-shaped tones, using normally connected speech?

Then read on to learn more about computers that recognize words, comprehend meaning from context, even synthesize human speech from a mere shadow of itself.

It's All In The Algorithms

Utilizing three levels of speech-processing algorithms, AT&T is giving the computer a more 'robust' understanding—the capacity to comprehend connected speech from different speakers.



Three levels to understanding

Acoustic pattern matching (1) identifies the spoken words.

Grammatical processing (2) figures out how the words are put together.

And semantic processing (3) extracts meaning from the context. With each successive step, the computer moves closer to accurate understanding.

Acoustic pattern matching determines how much latitude the waveform (pronunciation) of a word can have before it becomes unintelligible to the computer.

By isolating the specific characteristics the waveform of a word contains—independent of the accent of a speaker—we increase the probability that it will be correctly matched to a pattern stored in a computer's memory. But, correct recognition of words is only the beginning of computer understanding.

Computer Grammar 101

Grammatical processing further increases the probability of recognizing words. It analyzes them within the constraints imposed by language—the allowable sequences of syllables in a word or words in a sentence.

For a specific vocabulary and situation, it is possible to define every sequence the computer can recognize. Based on probabilities assigned to each word it recognizes—and where that word falls—the computer determines which of its possible sequences is the most likely. This process gains two advantages: It allows words that might not otherwise be recognized to be correctly accepted; and it speeds up processing time by using sequence position to limit the number of words it looks at for a pattern match.

A Meaningful Relationship

Semantic processing is the point where the computer crosses the line between recognition and understanding—the point where words are given meaning within a specific context. This endows a system with one of its most human qualities: knowing when a request isn't understood, and asking for appropriate clarification.

Talk Isn't Cheap

Making a computer listen intelligently is one thing; making it respond intelligibly, however, is another.

Enabling a computer to talk, reproducing the subtleties of human speech, has required large amounts of memory—a high cost item. Therefore, an 85 percent reduction in the amount of information needed to store and generate high-quality speech can mean significant cost reductions.

That's just what a new AT&T speech synthesis technique, called multi-pulse linear predictive coding (MP-LPC), provides. It reduces the 64 thousand bits per second previously needed to 96 hundred.

Speech signals mimic the human vocal tract—they have redundancies built in. MP-LPC codes speech to remove these redundancies, then tells the computer how to reconstitute the original speech from the mini-version in its memory. This coding eliminates unnecessary bits from being stored and transmitted.

Getting Down To Business

At AT&T, our goal is to make computers listen and understand as fast as people speak—and speak to and understand as many people as possible. Speech-processing algorithms, developed by AT&T Bell Laboratories, have moved us several steps closer to that ideal.

For example, most speech recognition systems make the speaker pause between words. But AT&T, using advanced recognition algorithms, has developed a Stock Quotation System, now in field trial, that allows callers to enter and retrieve current market information in natural, normally-connected speech. Users simply speak the number codes for any of over 6,000 stocks, and the service provides current quotes—delivered in computer-generated speech.

Numbers are nice, but make for limited conversation. Closer to our goal of a conversational computer is the Flight Information System. It uses the Official Airline Guide as its data base. In its limited environment, this laboratory system converses with the user in natural speech in response to normal flight information queries.

One Of Our First Callings

AT&T has been deeply involved in speech technology since the genesis of the telephone. From the beginning, our goal was to make mechanical communications fast, foolproof and economical.

Today, with the advent of the computer, we're moving toward the ultimate ideal: creating machines that serve our needs and save our energy in the most natural manner—by voice command.

AT&T

The right choice.

VOLTS FROM

Thin-film photovoltaic cells are starting to bring solar prices down to earth

by Tony Baer

The idea of turning sunlight into electricity inspires visions of a world freed from dependence on scarce and polluting fuels. But although solar cells—also called photovoltaic (PV) devices because they generate a voltage when exposed to light—have existed for more than three decades, their high cost has until recently restricted them mainly to such exotic uses as powering spacecraft. Commercial success is now coming, but in a less dramatic form than was once imagined. The Japanese, recognizing that there is more money in consumer products than in spaceships, are turning out millions of PV-equipped watches and calculators a month, and solar cells will soon appear on larger products, such as battery chargers, TVs, and automobile sunroofs.

Solar electricity is still expensive. PV cells cost roughly $10 per watt of generating capacity, several times more than a conventional power plant. But in contrast to other power sources, the "fuel" costs nothing and there are no moving parts to break down. Moreover, PV technology works well on any scale, so capacity can be expanded step by step.

The cost of PV cells has dropped enough so that they can now compete with diesel generators for power at remote sites—such as communications relays and water pumps—that are not hooked up to a utility grid. Solar cells are especially attractive in third world countries, where there are fewer central generating plants and where fuel prices can be exorbitant. In India, for example, diesel costs $4 a gallon.

Solar power's drop in cost—a tenfold reduction over the past decade—stems from a radical shift in photovoltaic technology. Invented at Bell Labs in 1954, solar cells were for many years made almost exclusively of the same ultrapure and expensive form of silicon crystals so ubiquitous in microelectronics (where the quantity of material per device is much smaller). But the Japanese have demonstrated that for many applications, especially where it's not that important to generate large amounts of power per square foot, cheaper and less refined materials are perfectly adequate. They can go onto less expensive substrates, be churned out more rapidly at looser tolerances, and cover areas much larger than those feasible for crystalline silicon devices. Furthermore, they can be manufactured with straightforward, highly controllable processes that are easily inte-

THE BLUE

One-foot-square panels coated with amorphous silicon—the most widely used thin-film material for converting sunlight to electricity—are readied for further processing at Chronar. A layer of metal will be evaporated onto the panels, forming an electrical contact to draw off the current.

grated into a continuous production line. Although the performance of these lower-cost PV devices does not yet approach that of the best commercial crytalline devices—which transform into electric power up to 15% of the solar energy that strikes them—some are coming close, and improvements are occurring steadily.

The leading low-cost approach involves thin films of semiconductor that are only 0.5–50 microns thick; "bulk" crystal devices, by contrast, measure 150–250 microns. Thin films soak up light as much as 100 times better than bulk crystals, thereby reducing the amount of material needed, and they offer less electrical resistance, simply because the electrons pass through less material on their way to the contact.

Thin-film PVs can be made from a variety of materials, such as cadmium telluride and gallium arsenide. But the favorite, which drives virtually all the solar-powered watches and calculators now on the market, is amorphous (noncrystalline) silicon. In 1985, over 8 megawatts worth of amorphous silicon PV devices were produced, according to Edward S. Sabisky, manager of the amorphous silicon program at the Solar Energy Research Institute (Golden, Colo.). Utilities are showing interest as well. Alabama Power, for example, plans to build an experimental power plant in which amorphous silicon solar cells generate 100 kilowatts.

Amorphous silicon is 40 times more light-absorbent than crystalline silicon; hence far less material is needed to produce useful power. But commercial amorphous devices are only 4–6% efficient. While several laboratories in the U.S. and Japan have reported small amorphous cells rated at 10–12%, this is still only about half as efficient as the best single-crystal silicon cells.

Much of the work on raising amorphous silicon's performance involves alloying with other materials. In any solar cell, electricity is generated only by those photons with enough energy to lift an electron from the valence band (in which state it is tightly linked to the atomic nucleus) into the conductive band; photons with energy lower than this "bandgap" value pass through the material with no effect. Amorphous silicon has a relatively high bandgap—1.7 electron-volts (eV)—resulting in a higher voltage. A crucial disadvantage, however, is that the cell produces a low current, since it responds only to high-

A solar cell primer

The photovoltaic effect, which underlies all solar cells, involves a semiconductor atom's outermost electrons. Silicon, the most common PV material, has four such "valence" electrons, which can be shared with neighboring atoms to form bonds. Heat or light can loosen the electrons so that they become mobile, and hence able to conduct. When that happens, the electron moves away from its parent atom, leaving a "hole" at its former position. In untreated materials, a freed electron would soon lose energy and fall back into this hole without any useful effect. To prevent such recombination, PV cells consist of junctions much like those in transistors and other electronic components.

Junctions are formed by doping—adding impurities—to change the electrical characteristics of the host material. One side of the device is made "n-type" by introducing atoms that contain one more valence electron than do the atoms of the host semiconductor; the other side is made "p-type" by doping with atoms having one fewer electron than the host. After doping, excess electrons on the n side spontaneously move across the junction to fill vacant sites on the p side, giving that region a net negative charge; excess holes move in the opposite direction, making the n side positively charged. The resulting charge imbalance creates an electric potential that the PV device needs in order to produce electricity.

The key to the photovoltaic effect is in the action of the electrons that have spilled over to the p side. When made conductive by absorbing light, electrons move across the junction toward the positively charged n side. There, electrical contacts can draw them off as usable current.

By far the major limitation on solar cell efficiency is poor matching with the solar spectrum. Sunlight consists of photons that carry a wide range of frequencies and hence a wide range of energies. A PV device, however, responds only to those photons with enough energy to lift a valence electron into the conductive band. Photons below this "bandgap" threshold pass through without effect. With higher-frequency photons, meanwhile, energy that exceeds the bandgap is wasted as heat.

The ability of a 1-micron thin film to soak up as much light as a 100-micron slab of crystalline silicon, and thus generate a comparable electrical output, comes from another factor: the type of bandgap, direct versus indirect. Crystalline silicon has an indirect bandgap; this means that when an electron absorbs a photon and jumps from the valence to the conduction band, it changes not only energy but also momentum. In order for overall momentum to be conserved, an electron can absorb a photon only when an additional particle, called a phonon, is formed in the crystal. By contrast, amorphous silicon and the other thin-film PV materials have direct bandgaps, in which electrons move between bands without changing momentum. Because they do not depend on phonon formation, these direct-bandgap materials are 100 to 1000 times as light-absorbent as bulk silicon.

Solar cell performance can be rated with values other than efficiency. One useful yardstick is the "fill factor." If a wire connects the cell's two terminals, maximum current flows (it's called short-circuit current). If the wire is cut, the voltage between the two terminals goes to its maximum value (open-circuit voltage). Drawing lines at these two values on a current/voltage plot forms a box. Because current times voltage equals power output, designers would like both values to remain high under all circuit conditions. The fill factor represents the portion of this theoretical box that is filled by the cell's actual performance curve. Thus a fill factor of 100% is ideal. In reality, however, current falls off as voltage rises to its open-circuit value; a fill factor of 80% is considered excellent.

energy photons (that is, photons toward the blue end of the spectrum). The much more abundant red and yellow photons lack the energy to make the electrons conductive.

Alloying amorphous silicon with another material can change its bandgap and thus broaden its response to cover more of the solar spectrum. In one particularly promising approach, two or three cells are stacked one on top of another, each alloyed to "tune" it to a different portion of the spectrum. The top cell may contain an element such as carbon that increases the bandgap, and the bottom layers could contain bandgap-reducing substances such as germanium. The silicon–carbon alloy intercepts the high-energy (blue and violet) photons; the remainder of the sunlight passes through to be absorbed in the silicon–germanium zone.

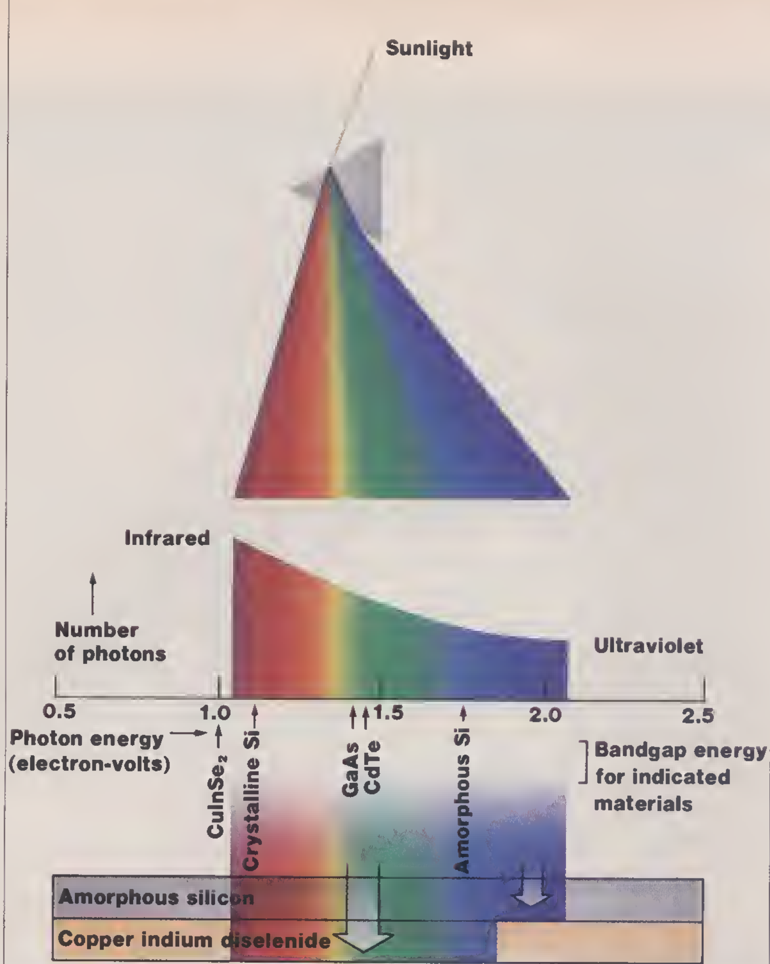
Such "multijunctions" can be produced either by passing the substrate from one deposition chamber to the next (the monolithic technique) or by fabricating individual cells separately and then stacking them mechanically. Monolithic cells lend themselves better to continuous mass production, but suffer from a severe constraint: with present fabrication techniques, a monolithic multijunction is limited to a single pair of electrical contacts, one at the top and one at the bottom. The problem with such a series hookup is that the output of the stack cannot exceed the smallest current produced by an individual cell. Designers must therefore adjust layer thicknesses so that each cell produces roughly the same current when exposed to typical sunlight conditions; any extra current will simply be wasted as heat.

Mechanically stacked cells can each carry their own set of contacts, avoiding the need for current matching. The additional contacts block some sunlight, however, and also complicate assembly because they render the device more fragile. These problems could be solved with the use of more transparent contact materials and with refinements in assembly techniques.

Multijunctions are responsible for the high performances of several laboratory devices. Energy Conversion Devices (ECD—Troy, Mich.), for example, has reported a 13% unit comprising a stack of three cells. The top two cells, consisting of unalloyed amorphous silicon, trap most of the blue light. The lower-energy red photons pass downward unimpeded and are absorbed in a bottom region of silicon–germanium alloy. ECD's next step will be to add yet another layer below the germanium alloy, with a still lower bandgap to catch more of the long-wavelength light.

There are also ways to soup up devices without using multijunctions. Sanyo, for example, has attained 11.5% efficiency in a single-junction PV by texturing the top layer of the cell to make it more absorbent, and by making the bottom contact reflective; as a result, incident light is trapped. In the U.S., Solarex (Rockville, Md.), a subsidiary of Amoco, has reported a 10.4% device using a "superlattice"; two materials with different bandgaps are deposited in extremely thin alternating layers near the top surface of the cell. Although high-quality American and Japanese prototypes are generally no larger than a square centimeter, several U.S. companies are now reporting square-foot prototypes in the 7–8% range.

But there is a dark cloud in the pic-



Thin films produce current only from the solar photons with energy exceeding a "bandgap" threshold. Stacking different materials thus broadens spectral response. In Arco Solar's scheme, amorphous silicon responds to blue and violet while copper indium diselenide catches the remaining sunlight.

MARK ALSOP

A technician at Energy Conversion Devices loads a 14-inch by 1000-foot roll of steel into a machine that will coat it with amorphous silicon to make photovoltaic cells.

ANDREW SACKS/BLACK STAR

ture: amorphous devices lose up to half their efficiency after a few weeks or months of exposure to the sun. After this plunge, efficiency appears to remain constant indefinitely. This effect has not hampered the most common use of amorphous silicon cells, because watches and calculators draw very little power; even the output of a degraded cell is enough. Yet the material's instability has been the main obstacle to its use in remote areas, where a spent cell could be hard to replace.

Opinions differ as to the cause of amorphous silicon's instability, but the prevailing view blames the fundamental character of the material. In crystalline silicon, every atom is strongly bonded to four other atoms to form an ordered, diamond-shaped lattice. In the amorphous state, by contrast, the silicon–silicon bonds are weaker, and the atoms assume a more jumbled arrangement, with many dangling bonds. These defective bonds trap electrons, reducing the current that reaches the cell's contacts. The problem gets worse over time, it is thought, because sun-energized electrons break more bonds. Meanwhile, however, sunlight heats the material, accelerating the formation of bonds. Efficiency eventually reaches equilibrium when this thermal healing balances the bond-breaking effect.

Happily, multijunction cells seem somewhat more stable than single-junction cells. One reason is that the introduction of alloys or dopants to form the different layers apparently relieves stresses that would otherwise break weak bonds. Also, because multijunction devices use thinner layers of material, electrons are less apt to encounter a dangling bond on their short journey to the circuit contact. And when they do, the electrons are less likely to be trapped, thanks to the more intense electric field that develops in a thinner layer than in a thicker slice at the same voltage. Consequently, the gradual increase in broken bonds has a comparatively small effect on the cell's output. ECD recently reported a triple-junction cell that retained 95% of its original 11% efficiency after several months of testing.

Another problem is manufacturing: production of all amorphous silicon cells, whether multijunction or not, is still a bottleneck. In the conventional process, silane gas (SiH_4) is decomposed by heat and radio-frequency discharge in the presence of a substrate. This "glow discharge" technique is slow, however, as well as subject to defects. While several alternatives are being studied, none seems capable of solving the speed and quality problems at once.

It's possible, for example, to accelerate the process by using disilane (Si_2H_6), which contains twice as much silicon as silane does; unfortunately, commercially available disilane is of uneven quality, besides being more expensive than silane. ECD claims that a 20-fold increase in deposition rate, to 0.01 micron per second, is possible by boosting the discharge frequency into the microwave regime. The microwave technique is experimental, however, and still has a relatively high defect rate. Other companies may scrap glow discharge altogether. Sanyo and Chronar (Princeton, N.J.) are investigating photochemical vapor deposition, using the energy of light to excite atoms and molecules. This

The high end of solar power

Not all the action in photovoltaic technology is in thin films. Many research groups are working with more traditional, single-crystal materials in efforts to fabricate much more efficient devices than would be possible with the inexpensive films. Since a comparatively small area of these high-performance devices is needed to generate a given wattage, they are being developed mainly for applications where real estate is at a premium. For example, the cost of the land occupied by solar panels is a significant factor when a utility weighs the economics of building a photovoltaic generating plant.

Most high-end PV cells are made of ultrapure silicon. When exposed to ordinary sunlight, silicon's maximum theoretical efficiency is around 25%. But performance can be increased if lenses or mirrors are used to focus light onto the device. Not only does such concentration increase the amount of solar energy striking the cell, but it results in a larger fraction of that light being converted into electricity. (The number of electron-trapping defects in the material remains constant as the number of photons increases.)

Researchers at Stanford have developed a device that combines 500-times concentration with other design innovations to make a cell of exceptional efficiency—27.5%. The heart of the device is a thin sliver of extremely pure silicon. The top surface is roughened and the back surface made reflective to trap up to 98% of all incident light. Contacts cover only about 2% of the overall cell area, versus 6–8% on conventional cells.

The utility-funded Electric Power Research Institute (EPRI—Palo Alto, Cal.), which sponsored the Stanford development, recently began working with Acrian, a San Jose semiconductor company, to commercialize the device. The goal is to achieve 29% efficiency and produce electricity at $2 per watt, by the early '90s.

An approach being pursued at the University of New South Wales (Australia) could result in 20% devices based on lower-quality (and less expensive) material. The passivated emitter solar cell (PESC) uses point contacts similar to those of the Stanford device, but with the rear contacts surrounded by a layer of heavily doped material. In effect, this "enhanced back field" forces electrons past the material's defects. With unconcentrated light, a PESC made of high-quality (semiconductor-grade) silicon displayed an efficiency of 20%. Significantly, efficiency almost as high—18.6%—was attained with a cell made of silicon containing 100 times as many impurities. The New South Wales group is now working with an Australian manufacturer to commercialize 15% modules.

Today's best silicon devices are more efficient than once thought possible. But continued improvements are not assured. "We have made the best cells we can with the existing silicon," says Ajeet Rohatgi of the Georgia Institute of Technology's electrical engineering department, who previously headed Westinghouse's major PV project. "In order to further improve silicon, we must find out what is 'wrong' with it first." Present theories do not adequately account for observed performance. One important barrier to high efficiency, for example, is the recombination of light-energized electrons with the "holes" they vacated in the material; but according to Rohatgi, recombination occurs more rapidly than predicted even in the best silicon, and it's not clear why.

Given silicon's uncertain chances for improvement, many researchers are pegging their hopes on gallium arsenide (GaAs) crystals. Already, the best GaAs cells are yielding 23% (26% with concentrated light), and the upper limit may lie in the mid-30s. Gallium arsenide is about 10 times as expensive per kilogram as silicon; but its greater light absorbency means that only a tenth as much material is needed, so device costs are comparable.

The multijunction concept that can be used to broaden the spectral response of thin films also works with crystals. In a device that developer Chevron Research (Richmond, Cal.) claims could reach 30% efficiency, for example, a cell of gallium arsenide phosphide (sensitive to blue light) rests on a GaAs cell alloyed with indium or antimony to catch longer-wavelength light. Chevron avoids the potential problems from mismatched crystal lattices by stacking the cells mechanically rather than growing one crystal onto the other.

Such stacking does not lend itself to economical mass production, though, so some researchers are developing ways to let mismatched lattices live with each other in so-called monolithic multijunctions. Varian (Palo Alto, Cal.), for example, recently produced a 13% GaAs device with consecutively deposited aluminum and indium alloys. The transition between materials is made gradual to minimize problems from mismatched lattices. Another approach is to separate the mismatched materials with a buffer, such as germanium, that is almost compatible with gallium arsenide.

Despite gallium arsenide's superior performance, production breakthroughs are needed if the material is to overcome silicon's 30-year technology lead. One promising innovation developed at MIT Lincoln Laboratory is now being commercialized by a start-up called Kopin (Taunton, Mass.). Thin films of single-crystal gallium arsenide are grown onto thick, reusable substrates of the same material and then sliced off when ready. Devices made with this process, which could deliver efficiencies topping 20%, would cost far less than cells composed of bulk gallium arsenide.

As a compromise between the high efficiency (and cost) of pure crystals and the low performance of thin films, silicon can be pulled continuously from a melt into polycrystalline sheets or ribbons. Such sheets have displayed qualities close to those of single-crystal silicon. Westinghouse's "dendritic web" process, for example, has produced 16–17% cells, but the process appears subject to contamination and tearing. Mobil Solar (Waltham, Mass.) has been working since the late '70s on a process for making relatively large ribbons (two inches wide), but has succeeded only in producing small batches. Solavolt (Phoenix), owned by Shell, plans to open a plant that will make 2 megawatts worth of polysilicon solar cells annually, using a vapor-based process that supposedly avoids the tearing associated with ribbons or sheets.

gentler method has been shown to give higher-quality material, but it is still slow.

Such problems have spurred interest in alternatives to amorphous silicon. The strongest competitor is copper indium diselenide ($CuInSe_2$), first developed as a PV material in 1980 at Boeing. In addition to being extremely stable, it is the most light-absorbent PV material known; nearly 99% of incident visible light is absorbed within the first half micron. Another advantage is that the electrons in $CuInSe_2$, when energized by falling photons, remain conductive a relatively long time before returning to the valence band. Thus, large proportions of light-generated charge carriers reach the contacts and contribute to the electrical output.

Although capable of generating fairly

large currents, copper indium diselenide is hampered by low voltage owing to a bandgap of only 1.0 eV. Largely because of the low voltage, efficiency gains have been slow in coming. Recent reports indicate that the material will be most useful in conjunction with other, higher-bandgap materials. Arco Solar (Chatsworth, Cal.), for example, has demonstrated a 12.5% device by stacking amorphous silicon on $CuInSe_2$. Cadmium sulfide could also serve as a high-bandgap companion.

Arco Solar VP Charles Gay predicts the company will reach efficiencies of 20–24% with modules combining amorphous silicon and copper indium diselenide.

ROB LEWINE

It may be possible, however, to increase the bandgap (hence the voltage) of copper indium diselenide itself. According to one theory, the cause of the material's low bandgap is a lopsided bonding arrangement; the copper–selenium bond is shorter than the indium–selenium one. This asymmetry may be lowering the bandgap by up to half an electron-volt. Labs at Boeing and elsewhere are working on alloying the material with gallium in the hope of evening out the bonds and thus raising the bandgap to 1.3–1.4 eV.

The second major problem with copper indium diselenide is its complicated fabrication process. At least three different gases are needed to form the compound. The process must be repeated many times, adjusting the proportion of copper and selenium to match the function of the layer being deposited. Boeing has reported little progress in scaling up its five-year-old chemical vapor deposition system, but promising alternatives are emerging. In a process called reactive sputtering, a stream of high-energy particles jars copper and indium atoms loose from a target. The ejected atoms pass through hydrogen selenide gas, where they react to form $CuInSe_2$ on a substrate. Arco Solar is thought to be using this technique, which is well suited to continuous production of large-area cells.

Another alternative, electrodeposition, is already well established in battery production and other industries. Copper is electroplated onto a substrate, followed by indium; finally, the mix is exposed to hydrogen selenide. The virtue is extreme control: "You can literally count atoms," says Vijay Kapur, whose year-old firm, International Solar Electric Technologies (Inglewood, Cal.), is now trying to commercialize the process. After only a few months of work, the company produced $CuInSe_2$ cells with a respectable 7% efficiency.

The leader in $CuInSe_2$ research is now Arco Solar, which has reported efficiencies of 13.1% for small laboratory devices and has built square-foot prototypes working at 7.1%. These modules contain 18 amorphous silicon cells laid out on a single large copper indium diselenide device. Innovations include electrodes of zinc oxide that are more transparent and conductive than the tin oxides used in other cells, and a gel—placed between the amorphous silicon and the copper indium diselenide—with a refractive index that compensates for light-bending that originates elsewhere in the device. These features allow more light to reach the bottom cell, boosting power output. Ultimately, Arco Solar expects to achieve efficiencies of 20–24%, says research vice-president Charles Gay.

Of the other materials attracting interest for PV applications, the leading contender is cadmium telluride (CdTe), which has neither the instability of amorphous silicon nor the low voltages of copper indium diselenide. Its bandgap of 1.4 eV makes it sensitive to most of the solar spectrum; in fact, efficiencies of almost 11% have been reported.

But producing CdTe is a major challenge. One problem is that deposition requires high temperatures (600–700° C), ruling out the use of some less rugged (and less expensive) substrate materials. Other difficulties stem from the need for precise control over the proportions of the two elements. A deviation of merely 1% in the ratio of cadmium to tellurium changes the material from n-type, where electrons (negatively charged) are the dominant current carriers, to p-type, where electron vacancies, or holes (positively charged), are in the majority. A PV cell needs both n and p regions in order to produce electricity (see "A solar cell primer"); CdTe is usually made p-type, while a transparent top layer of cadmium sulfide serves as the n-type re-

ECD president Stanford R. Ovshinsky with the company's amorphous silicon solar cells in the foreground. The material's biggest problem has been its loss of efficiency after exposure to sunlight, but ECD claims to have produced a stable 11% efficient device.

H GROSKINSKY

BUSINESS OUTLOOK

Consumer goods power photovoltaics

The market for photovoltaic (PV) cells—devices that convert sunlight to electricity—is currently undergoing a shift in applications, technologies, and leading players. Multimegawatt installations that produce power for sale to utilities accounted for less than 10% of last year's $170 million world market—down from 40% in 1983, according to Paul Maycock of Photovoltaic Energy Systems (Casanova, Va.), a market analysis firm. About 60% of the 1985 market went to communications relay stations, water pumping, remote residences, and other off-grid applications. Consumer electronics such as solar calculators, watches, and battery chargers accounted for 25% of sales; this fast-growing segment could claim almost half of a projected $480 million world market by 1990.

In 1985, Japan had 44% of the market, making it the leading producer of PV cells. The U.S. claimed 35% of the market. Atlantic Richfield's Arco Solar (Chatsworth, Cal.) is the world's largest PV manufacturer, with 20% of the market. The other major producers are Sanyo and Fuji of Japan and Amoco's Solarex (Rockville, Md.), each with 10–15% of the market. Other significant U.S. manufacturers include Motorola and Shell's Solavolt International (Phoenix), Pilkington Group's Solec International (Hawthorne, Cal.), Chronar (Princeton, N.J.), Energy Conversion Devices (Troy, Mich.), Mobil Oil's Mobil Solar (Waltham, Mass.), and Spire (Bedford, Mass.), a producer of PV fabrication equipment.

A number of factors lie behind these changes. Growth in the utility-based PV market, located almost entirely in the U.S., peaked in 1983 and has been dropping ever since. At an average price of $9–$12 per peak watt, solar systems are several times more expensive than conventional power sources, according to Robert Stele of Strategies Unlimited (Mountain View, Cal.). He predicts that unless solar cells become more efficient and cheaper to make, large-scale PV energy will remain uncompetitive for some time. Another drawback is that federal solar tax credits, used to subsidize PV installations, expired at the end of 1985 and are unlikely to be renewed.

Looking farther down the road,

ROB LEWINE

"Thin-film solar cells can easily be cut into small sizes, bent, and wrapped around curved surfaces. This flexibility opens numerous opportunities for us in consumer electronic applications."

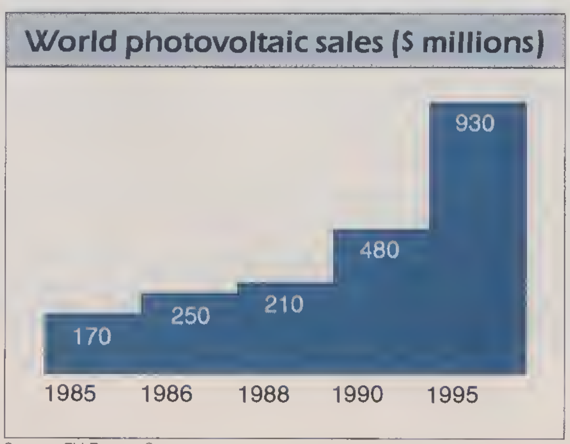
James Caldwell
President, Arco Solar

James Caldwell, president of Arco Solar, believes that "within five years, PV manufacturers should be able to cut prices in half. That will lead to a ten-fold growth in the market, particularly for utility and off-grid applications." Zoltan Kiss, president of Chronar, is also optimistic about the current interest of utility companies, at least in research-scale PV plants. "Utilities are aware that photovoltaic power could become more economical in the late 1990s, especially as electricity rates continue to rise, so they want to maintain their experience with PV," he says. "Falling oil prices will not affect this picture, since only 8% of U.S. electricity is generated by oil." In 1985, Chronar sold a 100-kilowatt PV system to Alabama Power and Light, and Arco Solar sold a 300-kilowatt system to the Electric Utility Dept. of the City of Austin (Tex.).

Meanwhile, PV firms are turning to more commercially viable markets, particularly for consumer products. The growing importance of the consumer sector is triggering a shift from single-crystal silicon, the industry standard, to amorphous silicon. Single-crystal silicon devices are relatively efficient and durable, making them most suitable for the outdoor market for power plants, communications equipment, and off-grid locations. In 1985, this material captured 44% of the world market, down from 50% in 1983, according to Maycock.

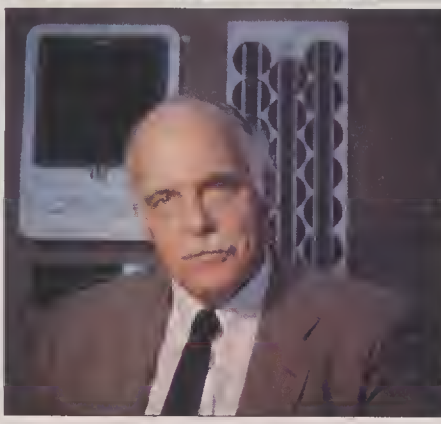
Amorphous silicon cells are less efficient and have yet to prove their durability in outdoor applications, but their light weight and low cost make them suitable for consumer products. In 1985 amorphous silicon constituted 35% of the market, up from 14% in 1983. Japanese companies took an early lead in commercializing amorphous silicon, but such U.S. firms as Chronar, Energy Conversion Devices, Arco Solar, and Solarex have also moved into this field. "The race now," says Stele, "is to develop new consumer product applications for this material as the market for solar calculators and watches becomes saturated."

Developing nations represent another potentially large, but problematic, market for PV systems. At villages and remote sites with no access to electrical grids, PV devices could power water pumps, refrigerators, communications facilities, and irrigation systems. But financial problems stand in the way of such third world applications. "The barrier here is not so much falling oil prices," says Arco Solar's Caldwell, "as lack of foreign exchange, high inflation, and uncertain availability of financing. When PV cell prices come down, international aid agencies may be more willing to finance PV imports."—***Kevin Finneran***

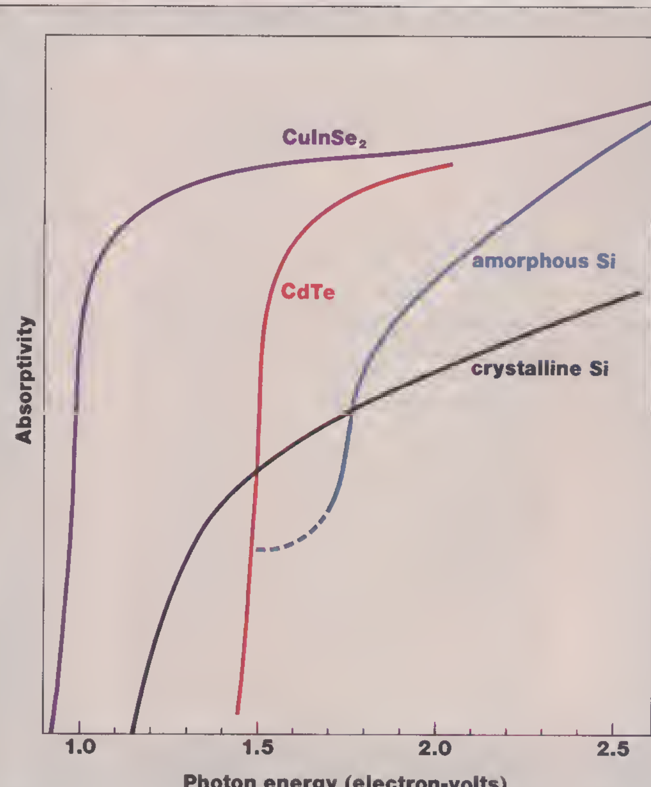


Source: PV Energy Systems

In an experimental version of Saab's 900 Turbo, rooftop solar cells power a ventilation fan when the car is parked. The stronger the sunlight, the faster the fan runs, lowering the initial air-conditioning load for a car that has been sitting in the sun.



Arco Solar alumnus William Yerkes hopes his start-up, Yerkes Electric Solar, will begin pilot production this summer of PV cells using cadmium telluride. CdTe is more stable than amorphous silicon and generates higher voltage than copper indium diselenide.



Thin-film materials vary widely in their ability to absorb light, but all are better absorbers than crystalline silicon.

gion. Unfortunately, control over the ratio is hampered by a large difference in vapor pressure between tellurium and cadmium.

One way around some of these fabrication problems is to use external dopants such as phosphorus and arsenic to create the n and p zones; the Cd/Te ratio can then be adjusted solely to minimize electrical resistivity. Some success with this method has been achieved by researchers at Arco Solar and by Ting Chu, professor of electrical engineering at Southern Methodist University (SMU) in Dallas. Arco Solar has produced small CdTe cells with 9.1% efficiency, and claims it can reach 15%. While the company has no immediate plans for commercialization, a spinoff does. Yerkes Electric Solar (Chatsworth, Cal.), recently started by Arco Solar alumnus William Yerkes, is developing a deposition process that Yerkes claims could run at temperatures well below 500° C. He hopes to start up a small pilot line this summer, supplying 4 × 6–inch custom cells for specialty products.

Another thin-film candidate, gallium arsenide (GaAs), is better known to the solar cell industry for its high performance in bulk crystalline form. Indeed, the highest efficiency ever attained by a PV device, 23%, came from a GaAs cell. The material's bandgap of 1.45 eV is optimal—allowing sensitivity to most of the solar spectrum while producing a reasonably high output voltage. Whereas amorphous silicon and $CuInSe_2$ probably will not exceed 15% efficiencies for single junctions, thin films of GaAs could top 20%.

Once more, however, the obstacle is fabrication. United Technologies (East Hartford, Conn.) tried growing single thin crystals of gallium arsenide on a low-cost, disposable substrate—ordinary table salt. But this process was still batch-oriented and slow. In another project, SMU tried depositing polycrystalline gallium arsenide onto graphite-coated tungsten. Unfortunately, the process required temperatures of over 1100° C, hot enough to melt away part of the substrate. Such failures have left GaAs as the darkest horse in the thin-film race.

For the near future, then, amorphous silicon will likely continue to rule the world of thin-film PV cells, despite the material's questionable stability and relatively low efficiency. Some solar-industry watchers predict that the Japanese, with their focus on supplying cells for mass-produced consumer products, will achieve such economies of scale that amorphous silicon devices will be only slightly more expensive than the glass or steel substrates on which they sit.

In the U.S., Arco Solar, ECD, and Chronar have each opened plants that can turn out a megawatt worth of amorphous cells per year. Solarex is operating a pilot facility, but parent company Amoco has not given the go-ahead for full-scale production. Meanwhile, Sanyo alone has an annual production capacity of 5 megawatts. Earlier Japanese efforts in amorphous silicon, together with the additional factories scheduled to come on line soon, will give Japan a strong advantage in the low end of the market for at least the next few years. □

Tony Baer is a New York–based science and technology writer.

For further information see **RESOURCES**, *p. 68.*

SMART CARDS

Using microchips, most financial transactions, plus many other activities, may be done with plastic

With the help of microelectronics, the ubiquitous credit card could acquire sophisticated new capabilities, providing a wide variety of services to consumers, businesspeople, and the financial community. The "smart card"—a plastic card containing one or more microchips—could become a tiny personal financial computer, programmed to keep records of an individual's bank and charge account balances and to initiate funds transfers directly to merchants and creditors. Such cards could take the place of both checkbooks and conventional credit cards. When used to pay for retail purchases, restaurant meals, tanks of gas, and even phone calls, cards could authorize the immediate transfer of money from cardholders' bank accounts to those of merchants. Or they could add charges to credit accounts, keeping running tallies as cardholders approach their credit limits. Smart cards are also under development for a variety of other purposes that range from storing patients' medical records during hospital stays to acting as electronic passkeys for restricted areas.

by Sarah Glazer

Already, dozens of pilot projects are under way around the world to test smart cards for specific applications, and in some cases cards have even been issued for permanent use. In France, where smart cards were pioneered, the national banking association has adopted them for use in credit and electronic payment transactions and has distributed several hundred thousand of the 12 million cards it expects to be in circulation there by 1989. In the U.S., MasterCard International began issuing smart cards last September to 70,000 of its customers in Columbia, Md., and Palm Beach, Fla., as part of a year-long pilot project to test them as possible replacements for conventional credit cards. And in Japan, more than 20 banks and large retailers are conducting similar but smaller-scale tests.

It took nearly a decade for smart cards, invented in the mid-1970s by a French company, Innovatron, to make their way out of the research lab. But by the early 1980s, pilot projects were under way in France to use them for such applications as postal money orders and prepaid tokens for public pay phones (both of which have since been adopted). The technology used in these early applications was still rudimentary; the chips had limited logic capabilities and memory. But with government backing and the participation of major manufacturers—Philips of the Netherlands and Flonic Schlumberger and the Bull Group of France—more ambitious tests were launched.

In 1982 a banking test began that eventually involved over 60,000 residents, 600 merchants, and local banks in the French cities of Blois, Caen, and Lyons. Smart cards were used as debit cards—essentially electronic checkbooks that allowed customers to transfer money directly from their own checking accounts to merchants' accounts. Participating merchants used special electronic terminals connected to a central banking computer to com-

MALYSZKO

municate the transaction data. A subsequent test, involving the same French and Dutch manufacturers, took place during the February 1985 World Ski Championships in the Italian town of Bormio. This time, 5000 smart cards distributed to ski officials, journalists, and residents were programmed as credit cards with $600 lines of credit. The cards' microprocessors kept track of charges and available credit, allowing merchants to authorize purchases without phoning for validation numbers; instead, they simply read the cards' records with special terminals.

What really gave smart card technology commercial credibility, according to Blair Shick, a senior consultant for Arthur D. Little (Cambridge, Mass.), was the decision of Japanese electronics giant Casio to enter the market in 1984, followed soon after by a covey of other Japanese manufacturers. "The market," he says, "finally began to take off internationally," launching a wave of business activity outside Europe. In the U.S., several overseas players sensed enough interest in both financial and other potential uses of cards to open subsidiaries: the Bull Group started Micro Card Technologies; Casio set up Casio Microcard; and the Schlumberger subsidiary Paymatek opened a smart card division in the U.S., as did the Swiss smart card maker Multimil. A number of independent American start-ups also arose, including SmartCard International, Intellicard International, and Smart Card Systems. And similar projects have been either launched or intensified at several established U.S. companies, including IBM and Motorola.

These card companies are selling or developing a variety of systems, ranging from cards that serve as individual file folders and ID cards for recipients of government benefits to cards that store lists of phone numbers and dial automatically from special phones. But by far the largest potential market will be for financial services, probably including both credit and debit features, contends Stephan Seidman, editor of *Smart Card Reports* (Mountain View, Cal.). Within five years, he estimates, more than 40 million such cards will be in circulation in the U.S. alone, and the cards will eventually be accepted in equipment as varied as gas pumps and parking meters. Cards developed for smaller-scale applications, such as those that allow access to restricted areas or those that hold special-purpose records, are being introduced at an even faster pace. Although these niche markets can accommodate a myriad of specialty manufacturers, says Seidman, a race is already taking shape to determine who will dominate the far larger arena for credit and debit cards.

Before long, smart cards may be commonplace substitutes for checks, cash, and most ordinary bank and credit cards.

The banking market beckons. It's ironic that bankers—a conservative lot, in general—are the driving force behind the adoption of a technology that could render their current credit card and electronic banking systems obsolete. But their enthusiasm is understandable, says Seidman, in view of the inherent costs of services that involve physically transporting pieces of paper—such as checks and credit card receipts—around the country and often around the world.

In France, where checks are much more widely used and are processed free of charge, banks have been anxious to prod their customers toward electronic payment systems, says Herve Nora, general manager of CP8, the Bull Group's smart card division (Trappes, France). And since phone service is comparatively expensive there, the lengthy calls required to validate conventional credit cards make them more expensive to use than in the United States. Smart cards, the French banking industry hopes, will provide an alternative acceptable to customers, merchants, and bankers alike. Because the cards can retain permanent records and updated balances for every transaction—becoming, in effect, electronic payment diaries—they give customers a convenient, self-balancing record file, allow merchants to run instant credit checks, and cut bankers' overhead costs.

However, there are two unresolved issues in the otherwise rosy picture, Nora acknowledges. For smart cards to be universally accepted, electronic readers must be installed in virtually

Inside smart cards

Smart cards, by definition, contain logic capability as well as memory. But why choose to put a relatively expensive microprocessor in a card when most of the current applications could be performed by cards that simply store and retrieve data? The answer lies in the cost of the electronic systems—the reading and writing terminals and computer network equipment—that support cards. Cards that include microprocessors are able to communicate with relatively inexpensive, "dumb" reading and writing terminals.

On-board logic also means that the data path between card and reader can be simple and standardized. So long as the input/output data stream of a card's microprocessor is compatible with the reader, the chip can have as simple or complex an internal structure as its purpose requires. For security, a microprocessor can encrypt its internal communications—so it polls its own memory in code—making its internal communication lines harder to tap. It can also give specified records confidential status, making them unreadable without special authorization codes.

Most cards being used and tested today contain either 4-bit or 8-bit microprocessors. The notable exceptions are French pay phone debit cards (which use simpler logic chips called programmable logic arrays) and optical memory cards (which don't have logic capability at all, relying instead on comparatively complex laser-based readers). But many manufacturers that use microprocessors are already considering upgrading them. "By the time there is a large-scale introduction in the U.S.," predicts Stephan Seidman, editor of *Smart Card Reports*, "we'll have a considerably more sophisticated card with enough programming capacity to be multifunctional."

Some cards contain single chips with combined logic and memory capacity, while others contain two or more separate chips—usually with distinct functions—connected by wire circuits. Most multichip cards have greater total memory space and logic capacity than current single-chip cards, but they're more complicated to manufacture and more vulnerable to tapping. Many companies that now make multichip cards simply "grabbed available off-the-shelf chips in order to get their testing programs going," says Jerome Svigals, publisher of *Smart Cards and Comments*. Most of these companies will soon switch to single custom chips to reduce manufacturing costs, he believes, but may eventually return to multichip designs to obtain the logic and memory capacities that sophisticated multifunctional cards will demand. By then, he predicts, designers will also have developed better scrambling techniques to make lines between chips harder to tap.

Another difference among today's cards is in data storage technologies. Vital data, including cardholder account numbers, secret passwords, and financial information such as account balances, must be stored in nonvolatile memory—circuits that don't lose their charge and "forget" as soon as they're disconnected from reading terminals. In order to update records, however, this memory must also be programmable. Most manufacturers are using either electrically programmable read-only memory (EPROM) chips or electrically erasable programmable read-only memory (EEPROM) chips. Because each address on EPROM chips can be written on only once, they provide permanent records of transactions, but they will also eventually become filled. EEPROM chips, on the other hand, give cards a longer life, because individual addresses can be erased and reused. However, Svigals notes that users will have to take care not to erase vital information if they intend to use the cards for personal record keeping.

every restaurant and retail establishment. Whether the cost will be borne by the banks, the merchants, or both remains undecided. And customers must be induced to use the new technology, which involves changing long-established habits and giving up the several-day "float" period they enjoy with checks. To encourage smart card use, some French banks have gone as far as instituting artificial floats.

Virtually all banking communities around the world have another incentive for finding an alternative to today's credit cards: the escalating industry-wide losses from fraud and bad debt, predicted by MasterCard to reach $2 billion annually by 1990. These losses and the authorization procedures required to control them constitute more than 30% of the costs of bank card transactions, according to results of a Visa and MasterCard study presented at an American Bankers Association conference last September.

Smart cards can incorporate a number of security features, starting with the personal identification number (PIN), a secret password used to verify a cardholder's identity. Unlike older PIN-based systems, such as automated teller machines activated by cards with magnetic stripes, a smart card can store the password and associated validation algorithms in its own memory, making the transmission of the password unnecessary. (Sending passwords over phone lines, possibly from thousands of stores and restaurants, would make a security system extremely vulnerable to tapping, notes Dan Miller, publisher of *Personal Identification News*, based in Washington, D.C.) To further discourage thieves, the cards can even be designed to shut themselves off after several incorrect passwords are tried. When used with readers connected by phone lines to a central computer, the card can be further grilled by the computer—made to produce additional codes and verify account balances before a transaction such as an electronic funds transfer can begin.

With smart cards now under consideration by the banking community worldwide, it's no surprise that card manufacturers are eager to penetrate the U.S. financial services market, with its enormous base of credit cards. MasterCard broke the ice last fall when it began its pilot project, conducted with the help of two manufacturers: Micro Card Technologies (MCT—Dallas), which is supplying the Palm Beach participants with cards and readers made in France, and Casio Microcard (New York), which is supplying the Columbia users with equipment made in Japan. The pilot project doesn't include debit card capabilities; it simply lets participating merchants verify customer identities and credit limits without phoning a central computer. Eventually, MasterCard hopes the cards will have more sophisticated financial functions and some nonfinancial ones as well—storing individual emergency medical information, for example. MasterCard claims that the test hasn't progressed far enough for evaluation, although one member of the project advisory committee reports that initial customer activity has been sluggish. To stimulate activity, the company is temporarily offering cardholders a free telephone for using their cards.

The two cards in the MasterCard pilot project are technically quite different; in fact, they are incompatible. They differ in placement of contacts, type of microprocessor, amount of memory (as well as method of access), and—perhaps most important—the data ex-

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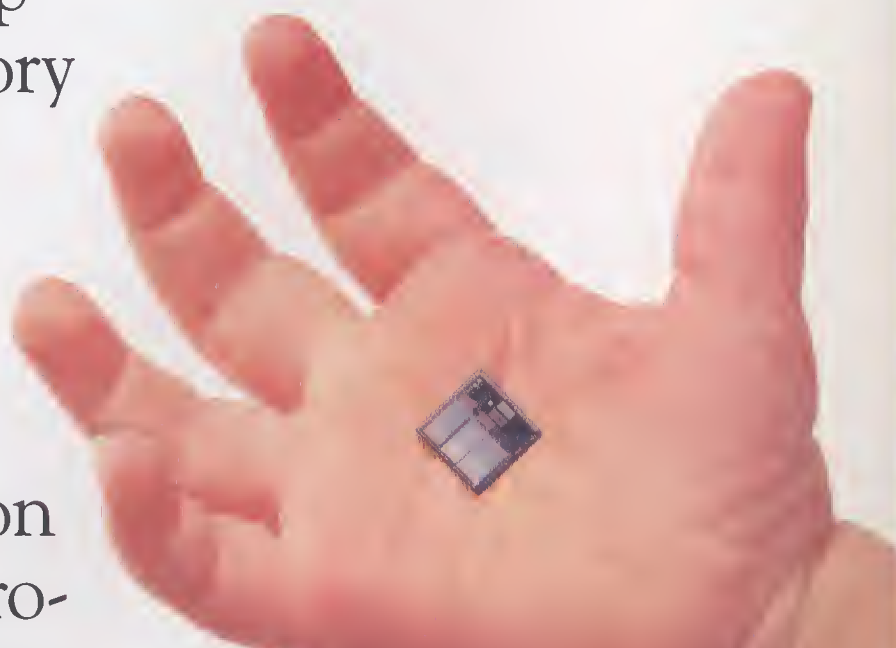

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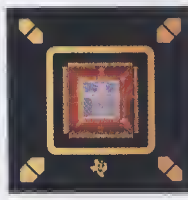

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▸ See back page for more information.

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†MegaChip IC size — .3937" x .3937"; actual package size — 1.75" x 1.75".

MIKE MALYSZKO

Smart cards are already being used not only for financial transactions but for applications ranging from pay phones to medical records. (The key-shaped cards allow access to restricted computers.)

change protocol for communicating with the outside world. While MCT president Richard Dunham downplays the difficulty of adapting existing designs to the standards he believes will eventually emerge, Casio Microcard president Robert Kitchner disagrees, contending that redesigns will be complicated. In any case, says ADL's Shick, the cards' incompatibility is causing intense competition between Bull (MCT's parent) and Casio—a state of affairs he terms "healthy for the overall industry."

Adding a keypad and display. Equally intense is the competition between MasterCard and its archrival, Visa International (San Mateo, Cal.). The same week MasterCard kicked off its pilot project, Visa tried a bit of one-upmanship by announcing its intention to develop a "supersmart" card, containing a keypad and liquid crystal display. In addition to being a credit or debit card, the proposed device will be a calculator, foreign currency converter, and electronic notepad and address book. These extra features will undoubtedly boost the price of such cards well above the $3–$5 that most manufacturers aim to charge (in large-volume orders) for simpler cards—sometimes called first-generation cards since the "super" designs were unveiled. But some industry watchers believe customers may be willing to pay a premium for the calculating and file-keeping capabilities, which could even include features like daily calorie-intake diaries. Visa announced last fall that it will be working on the cards with Japanese electronics company Toshiba, which is scheduled to deliver evaluation versions in 1987.

In May, Visa announced that it will also be testing prototypes from a small U.S. company, SmartCard International (New York), which is manufacturing the cards with the help of its corporate

RAY ELLIS

SmartCard International is adapting its keypad-and-display card to financial, medical, and government-benefits applications, says president Arlen Lessin.

ally General Instrument, an electronics company in nearby Hicksville, Long Island. These prototypes currently use five embedded chips, which give them substantial memory and processing capacity but also make them thicker than conventional credit cards. However, company president Arlen Lessin anticipates that the card's thickness will be reduced by switching to custom chips, of which fewer would be needed.

Another small U.S. company, Intellicard International (Colorado Springs, Colo.), is also making prototypes of a card with a keypad and display, although its current version has comparatively limited processing and memory capacity. One of the card's designers, William Abut-Jbara, says that the company is negotiating with several banks about possible test programs and is already developing cards for customers; a stock-brokerage firm, for example, is planning to use the cards to strengthen the security of an over-the-phone stock trading service now under development.

For cards used to pay for or charge retail purchases, one advantage of including a keypad and display is that transactions can take place without special card-reading equipment. Instead of using the keypad attached to a reader, cardholders can enter their PINs and indicate the form of payment to be used right on their own cards' keypads. The internal microprocessor can then run through its password validation algorithm, check the appropriate account balance, and generate a purchase authorization number on the spot. By then entering the price of the purchase on the keypad, the merchant can write the transaction into the card's memory, thus keeping account balances current. In order to be reimbursed, however, merchants would also have to phone or mail the purchase information to a central computer. And cardholders would probably have to use some type of on-line device—a networked card reader or an automated teller machine, or possibly a personal computer—to reset their credit limits after making payments and to record deposits made into their bank accounts.

A drawback to these keypad-and-display cards is that the lack of computer supervision could increase the possibility of fraud. "How will a clerk know that a device, and therefore the authorization number it generates, isn't counterfeit?" asks Jerome Svigals, publisher of the newsletter *Smart Cards and Comments* (Woodside, Cal.) and chairman of the American National Standards Institute (ANSI) committee on smart card banking standards. Safeguards can be built in, he stresses, but they will probably require the clerk to enter additional security codes, making financial transactions less automated.

But there's still plenty of time for design refinements, Svigals believes, because a prerequisite for widespread use of smart card credit or debit systems—throughout the U.S. and the world—is the adoption of international standards. The banking community is unanimous, he says, in wanting every card issued to be universally readable by electronic cash registers, point-of-sale terminals, and automated teller machines. Svigals estimates that banking standards, under review by the International Standards Organization (ISO) and the National Bureau of Standards as well as by ANSI, are at least two or three years away. Standards covering physical characteristics, including the location of contacts and the nature of electrical signals passing between cards and readers, are in the process of being ratified this year, both by ANSI and ISO. But work has just begun on standardizing the data protocols necessary to implement credit and debit transactions. *Smart Card Reports*' Seidman observes that the lack of international standards certainly hasn't stopped the French from instituting smart cards for banking—and he predicts that it may not deter the Japanese either. But both countries should be prepared to redesign their systems, he cautions, if they eventually find themselves at odds with internationally ratified standards.

Other applications abound. The lack of standards is of little significance for many other smart-card applications, which—unlike credit and debit systems—don't depend on widespread compatibility. For example, cards are already being used in security systems that restrict access to buildings or computers. Multimil supplies cards and readers to another Swiss company, Gretag, for use in units that restrict access to insurance and banking industry computer networks. A small U.S. company called Datakey (Burnsville, Minn.) makes a variety of chip-based devices for security applications, although they are key-shaped or tag-shaped rather than card-shaped. Most are used for selective access to computer or telecommunications equipment, but one device has been designed to keep dialysis patients from receiving treatment at the wrong artificial kidney machine—and automatically adjusts the machine's settings and keeps a log of the patient's treatments. But perhaps the most sophisticated security application thus far, being developed by Indentix (Palo Alto, Cal.) with cards supplied by Micro Card Technologies, verifies someone's identity by comparing the person's fingerprint with a digitized version of the print stored in the card memory.

Several companies are working on card systems for use in hospitals, to contain—and cross-reference—information such as test results and prescribed medication. Blue Cross and Blue Shield of Maryland has launched a large-scale test of cards that hold a patient's entire medical history and insurance coverage, although the card it chose, made by Drexler Technology (Mountain View, Cal.), does not contain chips. Instead, it has an optical memory, capable of holding 800 pages of data (including digitized x-rays or EKG readings), and is written on and read by a laser. Blue Cross and Blue Shield has already ordered 150,000 cards and 60,000 terminals and expects to distribute 1.6 million cards in 1987.

In France, the telecommunications ministry is replacing coin-operated telephones with units operated by disposable cards (made by Paymatek Schlumberger) programmed to pay for several calls. A deterrent to vandalism, the new phones are scheduled to replace 50% of France's pay phones by 1990, according to government timetables. In England, a cable TV company, Paytel, makes pay-per-view television equipment operated by debit cards (made by Multimil).

Smart cards are also being applied to a variety of record-keeping purposes in closed environments. The U.S. Navy is using cards made by Smart Card Systems (Cherry Hill, N.J.) to simplify its purchasing procedures. A branch of the University of Paris uses cards from Bull for its student transcripts. Dai Nippon, a Japanese electronics company, is using its own cards to deliver computer game software. And the Pentagon has proposed using smart cards to replace the metal dogtags worn by all its personnel.

In the cards. Over the next few years, many of these single-purpose cards will be superseded by more sophisticated versions, according to *Smart Card Reports*' Seidman. And their greater memory and programming capacity will make them versatile enough to serve a variety of purposes. Eventually, says Seidman, "there will be some central agency making a universal card" and selling space on it for applications that range from "making phone calls and operating parking meters to paying restaurant bills." Already, in fact, the French banking industry is considering diversifying its card functions and renting memory space to the airline industry to use in place of their own charge cards, says Bull's Nora. Internationally, says Seidman, Visa and MasterCard are vying to dominate this universal card market,

RAY ELLIS

DAVID BUFFINGTON

Casio Microcard president Robert Kitchner (top) and Micro Card Technologies president Richard Dunham (bottom) each hope that their company's role in MasterCard's major test project, supplying cards and readers for half the participants, will help it corner the bank and credit card market.

but may eventually face competition from companies not currently in the credit card business, such as electronics or computer manufacturers.

Smart card distribution should begin in earnest within five years, estimates *Smart Cards and Comments* publisher Svigals. Eventually, he says, cards could well be manufactured in massive numbers; putting a smart card in every wallet could mean a market "measured in the billions." Svigals points to the example of magnetic stripe cards. When these were first introduced, he says, it took seven years of testing before standards were finally adopted. Now, more than a decade later, almost a billion are in circulation for financial transactions alone.

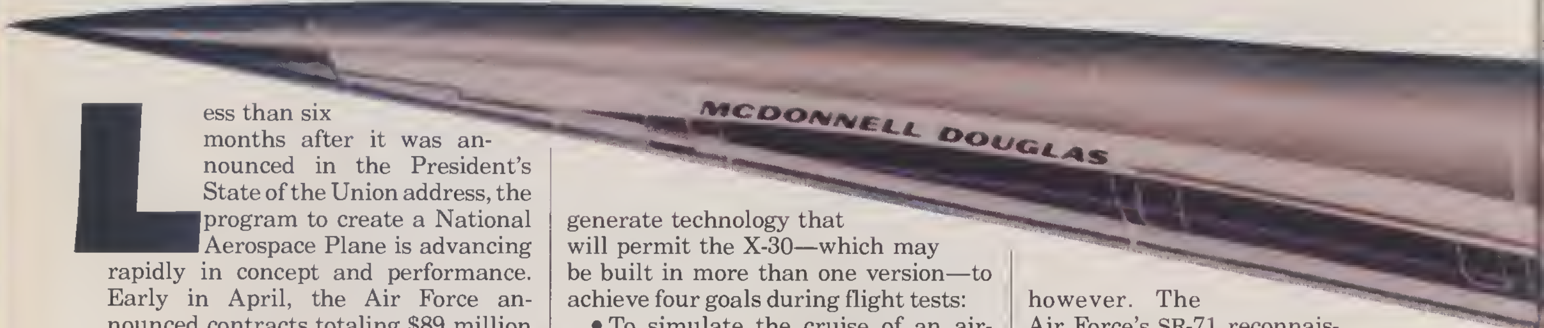
With such a huge potential market, competition will intensify among card manufacturers as well as issuers. Some observers predict that the Japanese will soon take over the market, as they have with so many other high-volume consumer electronic products. But Svigals isn't ready to count out the French. They have the know-how to stay ahead of the Japanese technically, he says, but will have to keep innovating at a fast clip to survive. Seidman agrees that U.S. manufacturers—both small and large—may already have been outdistanced in the race shaping up for high-volume contracts. "It's a business that will require a lot of manufacturing experience," he says, and so far most of the experience is being gained by Japanese and French companies. "U.S. electronics manufacturers are too short-range oriented" to invest heavily in a market that is still several years from significant volume. That's not to say, though, that the innovative designs coming from many quarters in the United States today won't find their way into the mass market, whether through joint ventures with their developers, through acquisitions, or through licensing agreements. The rising level of business activity has already spurred a burst of technical development, says Seidman, "and there will undoubtedly be many more creative ideas" coming from a variety of sources as smart cards enter the commercial mainstream. □

Sarah Glazer is a senior business editor of HIGH TECHNOLOGY.

For further information see **RESOURCES,** *p. 68.*

Launching the

◆ R&D has begun on hypersonic craft that



Less than six months after it was announced in the President's State of the Union address, the program to create a National Aerospace Plane is advancing rapidly in concept and performance. Early in April, the Air Force announced contracts totaling $89 million for initial work on a 42-month, $700 million effort to design an airplane/spacecraft hybrid. Starting in late 1989—if the key technologies are adequately demonstrated—program directors plan to spend $2–3 billion to build several research craft, of a type recently designated by the Air Force as the X-30, that will begin flight tests in the mid-1990s.

That experimental plane should point the way to production craft that will revolutionize military and civilian flight. General Lawrence Skantze, head of the Air Force Systems Command, foresees an aerospace plane with "the speed of an ICBM and the flexibility and recallability of a bomber." Such a craft "could sit alert like a B-52," he says, and perform quick-response reconnaissance as well. And it could lower the cost of space launches by a factor of 10 to 20, to meet the deployment needs of the Strategic Defense Initiative.

Meanwhile, the advanced-design group at McDonnell Douglas (St. Louis) has conceived the idea of an "Orient Express" that will carry more than 300 passengers across the Pacific in two hours, at Mach 5.5. The company's economic analyses, based on a model tested against data from operations of the Boeing 747, suggest that the Orient Express could be profitable early in the 21st century at the same ticket prices as jumbo jets, by making four flights a day. Only slightly farther ahead lie commercial craft that may carry tourists to orbiting hotels.

Laying the foundations for such craft demands major progress in three aeronautical technologies: engines, structures, and thermal management. In particular, the Defense Advanced Research Projects Agency (DARPA—Arlington, Va.), which is administering the 42-month design phase, hopes to generate technology that will permit the X-30—which may be built in more than one version—to achieve four goals during flight tests:

- To simulate the cruise of an airplane for extended durations at speeds between Mach 5 and Mach 10 and altitudes well above 100,000 feet.
- To demonstrate, by operating from flight-test centers (including Edwards Air Force Base in southern California), that such craft can fly into and out of ordinary airports. These tests will also focus on the environmental acceptability of hypersonic transports. For example, by having the X-30 climb out at steep angles over the ocean, it may be possible to prevent its sonic boom from hitting populated areas.
- To demonstrate flight into orbit from a runway, powered by air-breathing engines and carrying several thousand pounds of instruments. Runway locations may include Cape Kennedy and southern California's Vandenberg Air Force Base.
- To establish rapid turnaround in space operations. "The thing we most want to achieve, perhaps even more than maximizing the payload fraction to orbit, is quick turnaround time," says Robert Williams, DARPA's program manager for hypersonics and the director of the aerospace plane project, "You would really like to get to the point where you could land one of these vehicles and go again in a few hours."

How practical are these goals? Recent history suggests that they are extremely ambitious. In the 1960s, technical difficulties killed an Air Force concept called the Aerospaceplane, which was to fly to orbit using air-breathing jet engines. The cancellation of Boeing's supersonic transport in 1971 squelched that company's studies of a more advanced transport that could have flown at hypersonic speeds (above Mach 5). NASA's view, expressed in the early 1970s, that the Space Shuttle would make orbital flight routine was hopelessly unrealistic even before the *Challenger* disaster.

The picture isn't necessarily bleak, however. The Air Force's SR-71 reconnaissance aircraft, first built in the 1960s by Lockheed (Burbank, Cal.), can approach hypersonic flight, with a speed of at least Mach 3.3 and a cruising altitude of at least 100,000 feet. Its faults and merits indicate ways of achieving the aerospace plane's goals.

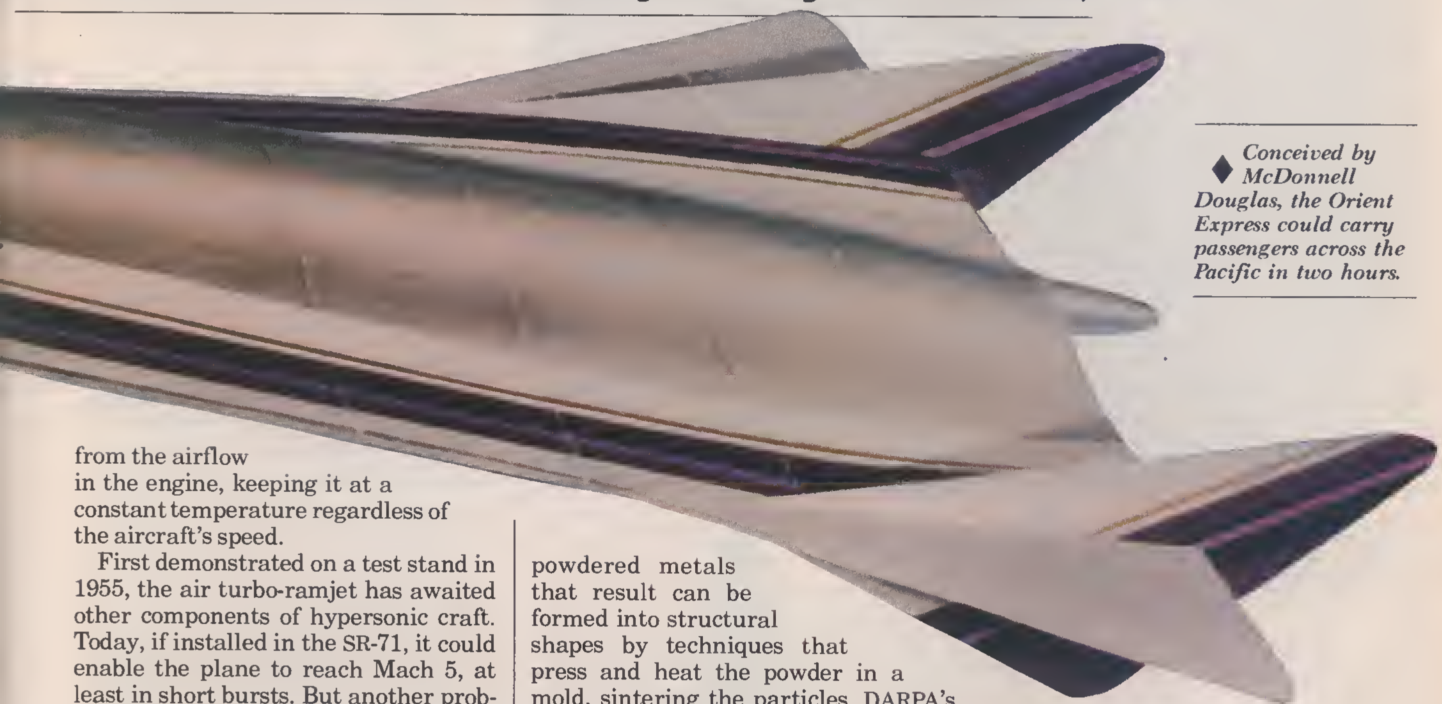
The SR-71's engine, the J-58 built by Pratt & Whitney (East Hartford, Conn.), is essentially a conventional turbojet augmented with an afterburner (a device that ignites exhaust gases for added thrust). A normal turbojet engine's performance at high speeds is limited by overheating of the turbine, which spins in the jet exhaust. This heating arises from two sources: the burning of fuel to produce thrust, and frictional aerodynamic heating that results when supersonic air outside the engine slows down to subsonic speeds inside—a necessity if the engine's compressor and fuel injector are to work properly. The J-58 partly avoids this limit by bypassing its turbine and compressor at high speeds. A set of ducts leads directly from the engine inlet to the afterburner, which thus acts as a ramjet—a jet engine into which the air rushes so fast that it doesn't need a compressor. The hot parts of a ramjet can be cooled with circulating fuel, just as water circulating in channels cools the block of an auto engine. Thus the limiting factor for a ramjet is not heating but a decrease in fuel efficiency; at about 2700° F, molecules of fuel and air dissociate, breaking up into unburned and partly burned particles.

Aerojet Techsystems (Sacramento, Cal.) has developed a combination turbojet/ramjet engine that will soon be ground-tested at NASA's Lewis Research Center in Cleveland. The air turbo-ramjet, as it is known, uses a gaseous fuel, such as hydrogen or methane, which cools the engine's hot parts and then spins a turbine before being burned. This design isolates the turbine

by T. A. Heppenheimer

aerospace plane

would take off from a runway and fly into orbit ♦



♦ *Conceived by McDonnell Douglas, the Orient Express could carry passengers across the Pacific in two hours.*

from the airflow in the engine, keeping it at a constant temperature regardless of the aircraft's speed.

First demonstrated on a test stand in 1955, the air turbo-ramjet has awaited other components of hypersonic craft. Today, if installed in the SR-71, it could enable the plane to reach Mach 5, at least in short bursts. But another problem prevents this aircraft from making long flights at such speed. During sustained flight, aerodynamic heat created by friction soaks into the craft's skin, and then into the fuel. Beyond the relatively low temperature of 690° F, the fuel becomes chemically unstable, forcing the SR-71 to land.

Insulation should overcome that problem. The Lewis Research Center has developed a fuel tank insulated by a combination of high vacuum and layers of aluminized Mylar or Kapton plastic. So effective is the insulation that it makes it possible to substitute highly efficient liquid hydrogen or liquid methane for the boron and hydrocarbon JP7 high-temperature fuel that the SR-71 burns.

Another obstacle to sustained hypersonic flight is that the titanium alloy skin of the SR-71 starts to weaken at about 1000° F, a temperature reached after a few seconds at Mach 5. Traditionally, designers have relied on nickel alloys to overcome that effect; but while these materials are more temperature-resistant than titanium, they are also much heavier. Now, a DARPA-developed process called rapid solidification offers the prospect of titanium alloys with the heat-resistance of nickel. The process quenches molten drops of alloy through thousands of degrees in a few milliseconds by exposing them to streams of cool helium gas. The powdered metals that result can be formed into structural shapes by techniques that press and heat the powder in a mold, sintering the particles. DARPA's Williams maintains that such materials "are reaching a fairly mature state"; in fact, McDonnell Douglas proposes to use them for its Orient Express.

Employing the air turbo-ramjet and rapid-solidification metallurgy, the Air Force might build interceptors capable of Mach 5 or 6; indeed, it built a Mach 3 prototype—the YF-12, a variant of the SR-71—in 1963 but did not develop it further. If the Soviets sent supersonic Blackjack bombers on a mission out of Murmansk, Mach 6 interceptors could cross the Atlantic in less than an hour and meet them over the North Sea.

Today, DARPA views SR-71 technology as largely obsolescent. In the experimental X-30, the agency is focusing on something far more advanced: an ascent-to-orbit aircraft that will substantially boost the technology of hypersonic cruise, as well as provide commercial spinoff.

The stimulus for the vehicle is the fact that rockets are notoriously inefficient in reaching orbit, typically carrying all their oxidizer as tanks of liquid oxygen. The Space Shuttle, for example, carries 666 tons of oxygen, 28 times its maximum payload. Ironically, a rocket expends at least half its fuel in reaching Mach 6, during which time there is oxygen aplenty in the surrounding atmosphere. Might not a launch vehicle achieve great payload gains by breathing air rather than carrying oxygen in a tank?

Inevitably, it's not that simple. Design studies have shown that the weight increase offsets the potential payload gains. A rocket's structure is simple—it is a cylinder that bears weight predominantly along its length as it lifts off and accelerates. A conventional air-breathing craft, by contrast, gains its lift from the fuselage and wings, which weigh considerably more than a rocket's simple cylinder.

There would be other sources of additional weight as well. The air-breathing engines are heavier than rockets of equal thrust, for the rocket is unexcelled in thrust-to-weight ratio. Moreover, the craft would have to carry the burden of both types of engine at the same time, since traditional air-breathing engines poop out at about Mach 6, necessitating a switch to rocket power; whichever engine was not in use would simply be dead weight.

The resulting aerospace plane could weigh in the neighborhood of 2 million pounds, far exceeding the few hundred thousand pounds of a conventional large airplane. That could necessitate enormous—and heavy—spreading wings to lift the craft from a runway. For example, a proposed aerospace plane called Star-Raker, studied at Rockwell International in the late 1970s, was to weigh 5 million pounds

Paul Czysz, chief scientist for the Orient Express, sees profitable operation for his plane early next century.

fueled and loaded, and 775,000 pounds empty. Huge delta wings would have carried it to orbit, with 126,000 pounds of payload—2.5% of its liftoff weight. Such a behemoth would represent only a marginal improvement over the shuttle.

By contrast, one concept now envisioned weighs 150,000 pounds empty, scarcely heavier than a DC-10. It would carry 30,000 pounds to orbit, starting off with just 211,000 pounds of fuel. The key is a combination of jet engines, rocket engines, materials, and thermal protection technology that would act synergistically to minimize weight.

How can designers achieve this? The pacing technology is propulsion. On April 7, DARPA announced two contracts for the preliminary design of full-size supersonic-combustion ramjet, or scramjet, engines (in which inrushing air maintains its supersonic speed, reducing aerodynamic heating). Pratt & Whitney's Government Products Division (West Palm Beach, Fla.) received one, for \$28.5 million; the other, for \$26 million, went to General Electric's Aircraft Engine Group (Cincinnati). The reason for the double sourcing: DARPA's Williams says he wants to stimulate engineering competition and thus reduce the technical risks, while laying the foundation of a scramjet industry.

Between June 1987, when those contracts end, and late 1989, the two firms will probably receive further contracts, up to a total value of \$175 million per company. Those will cover the development and fabrication of prototype scramjets suitable for the X-30. The final product from each firm, in 1989, will be a prototype engine module, some three feet across and 10–15 feet long, that produces thrust of 2000–3000 pounds. Eight to twelve of the engines in a band will girdle the underside of the X-30 when it is built.

Throughout the engine development, designers will use supercomputers in combination with wind tunnels (HIGH TECHNOLOGY, April 1986, p. 62). Indeed, supercomputers are one of the main reasons DARPA is pursuing the aerospace plane today. While design concepts were available for many elements of the program a decade ago, the available design methods entailed approximations that would have been too expensive to iron out in actual prototypes.

The DARPA program will also provide a new ground-test facility. Aerojet Techsystems, Marquardt (Van Nuys, Cal.), and Martin Marietta (Orlando, Fla.) are bidding to build a wind tunnel several feet in diameter, capable of testing full-size scramjet engines at Mach 8. Meanwhile, the program may use a similar wind tunnel, eight feet in diameter, at NASA's Langley Research Center (Hampton, Va.). And it will run tests in the six-foot shock tunnel at Calspan (Buffalo), which can produce flows at Mach 20 for 10 milliseconds—a relatively long time when monitored by high-speed instruments, although simulating the planes' actual performance at this stage relies on extrapolation.

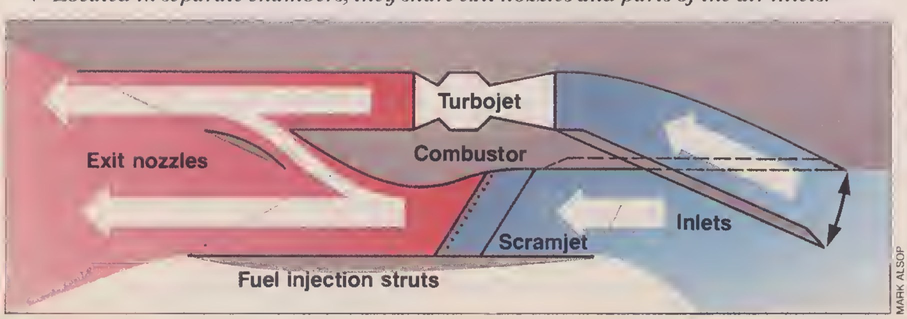
Certainly the scramjet will need all the help it can get, for its ascent to orbit will resemble the perils of Pauline. The problems start literally on the runway, where the X-30 will need a sufficient boost from a lightweight auxiliary propulsion system to push it up to the Mach 3 speed at which the scramjets can operate efficiently. They don't end until the final thrust into orbit, which will demand auxiliary rocket power.

The air turbo-ramjet might be used to get the aerospace plane off the ground. In addition, NASA has recently proposed an integrated package—a turbojet and scramjet in separate compartments that share an exhaust nozzle and some elements of the inlet. The turbojet occupies the upper chamber, ready to come into play during both acceleration and landing approach. Above Mach 3 it represents an unavoidable dead weight. But modern turbojet technology permits smaller and lighter engines than those previously available.

Crucial to the engine package is a "variable geometry" inlet—similar to that aboard the SR-71—whose parts move to take up different positions as the Mach number increases. Such close control is necessary because supersonic inlets are highly temperamental. Any departure from the exact design conditions can cause the airflow in the engine to break down, resulting in a sudden collapse of thrust (called an unstart).

Work at Langley Research Center is believed to have preemptively solved the next peril—the tendency, at speeds up to Mach 7, of injected fuel to blow out of the exhaust before it can ignite.

NASA's proposal for the aerospace plane's engine combines a turbojet and a scramjet. Located in separate chambers, they share exit nozzles and parts of the air inlets.



Rapid turnaround is the main goal for the aerospace plane, says program manager Robert Williams of DARPA.


CHARLES BORNIGER

NASA combats the effect with a heat-resistant strut that crosses the scramjet's interior and injects hydrogen fuel directly into the airstream. Because the hydrogen has already circulated to cool hot engine parts, it has absorbed enough heat to mix and burn readily. Garrett AiResearch (Torrance, Cal.) is fabricating a full-size strut, to be tested in Langley's eight-foot wind tunnel.

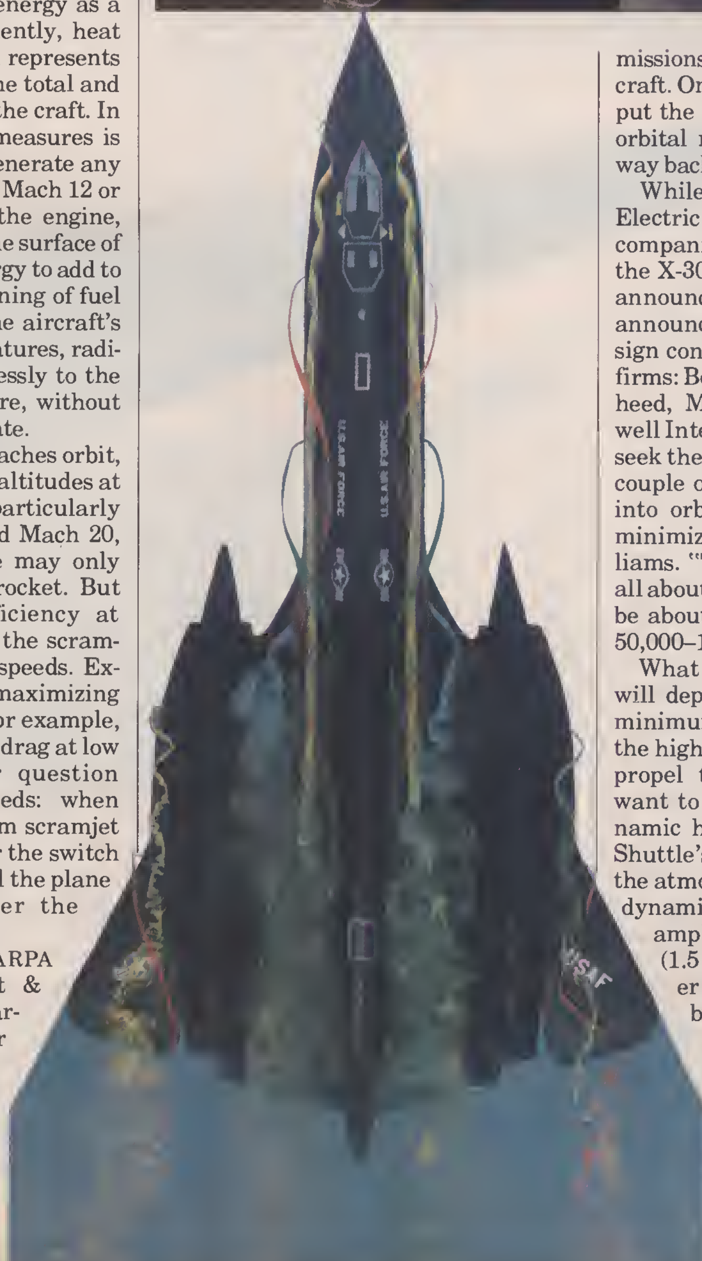
As speeds increase, the scramjet's performance falls off. At its peak of Mach 4, it can burn fuel eight times as efficiently as a rocket, but by Mach 12 it has only a threefold advantage. This falloff appears unavoidable. A scramjet is a heat engine; it works by adding energy to the airstream in the form of heat from burning fuel. At high Mach numbers the airstream already possesses considerable kinetic energy as a result of its speed. Consequently, heat added by the burning of fuel represents a decreasing proportion of the total and is less effective in powering the craft. In fact, a fairly heroic set of measures is needed for the scramjet to generate any acceleration at speeds above Mach 12 or 14. Instead of cooling just the engine, circulating fluid must cool the surface of the aircraft and recover energy to add to the fuel. Otherwise, the burning of fuel would serve only to keep the aircraft's surface at steel-mill temperatures, radiating the fuel's energy uselessly to the cold of the upper atmosphere, without causing the plane to accelerate.

Finally, as the craft approaches orbit, its trajectory will carry it to altitudes at which the air becomes particularly thin. Here, at speeds around Mach 20, the scramjet's performance may only slightly surpass that of a rocket. But designs that improve efficiency at Mach 20 inevitably worsen the scramjet's performance at lower speeds. Excessively large inlets for maximizing fuel efficiency at Mach 20, for example, would significantly increase drag at low Mach numbers. Another question arises at near-orbital speeds: when should the plane switch from scramjet to rocket thrust? The earlier the switch is made, the more rocket fuel the plane must carry. But the later the switch, the larger the inlets.

What rocket will DARPA choose? Quite likely Pratt & Whitney's RL-10. This 25-year-old engine has the proper thrust—15,000 pounds—for the intended weight of the aerospace plane and has proved itself in use, having boosted planetary missions such as the Voyager spacecraft. One or two RL-10s would suffice to put the craft into orbit, guide it during orbital maneuvers, and start it on its way back into the atmosphere.

While Pratt & Whitney and General Electric are developing engines, other companies will focus on the structure of the X-30. On the same day that DARPA announced the engine contracts, it also announced $7 million conceptual design contracts for each of five airframe firms: Boeing, General Dynamics, Lockheed, McDonnell Douglas, and Rockwell International. The contractors will seek the lightest design that can carry a couple of tons of research instruments into orbit. "We would clearly like to minimize the weight," declares Williams. "That's what the competition is all about." He expects that the X-30 will be about the size of a DC-9 and weigh 50,000–100,000 pounds fully loaded.

What will the X-30 look like? That will depend on trade-offs. One goal is minimum drag; the lower that figure, the higher and faster the scramjets will propel the craft. But designers also want to reduce the amount of aerodynamic heating on reentry. The Space Shuttle's method of belly-flopping into the atmosphere nose-high reduces aerodynamic heating considerably, for example, but at the expense of a low (1.5 to 1) lift-to-drag ratio. If greater heating is acceptable, it might be possible to use a shape in



The Air Force's SR-71 comes closer to hypersonic flight than any aircraft now flying. It reaches at least Mach 3.3.

♦ Orbiting in style: Britain looks to Rolls Royce

The U.S. doesn't stand alone in exploring a space plane. In February, the British government announced that it would provide $4.2 million for proof-of-concept studies on the HOTOL, an automated, reusable horizontal takeoff and landing craft designed by British Aerospace to fly directly to orbit from a conventional runway.

HOTOL differs in several ways from the U.S. National Aerospace Plane. It will use an air-breathing engine only up to a speed of Mach 5, for example, at which point it will switch over to rocket power for the rest of its journey to orbit. Both forms of propulsion will use liquid hydrogen as their fuel. For takeoff, HOTOL will be mounted on a rapidly moving trolley, which will release the space plane at a speed of 290 knots. On its return from orbit, the craft will enter the atmosphere belly first, like the Space Shuttle, to reduce the effects of aerodynamic heating. The orbital version of HOTOL is designed to be unmanned; but designers also hope to fit HOTOL with a cabin that will hold 60 passengers for 70-minute trips between Europe and Australia.

What has drawn the most attention in the aerospace world is HOTOL's engine, to be built by Rolls Royce. "During the 1960s, some 54 different concepts were proposed for air breathers," says Alan Boyd, the engine's inventor. "We found a 55th." Fearing the possibility of industrial piracy, British Aerospace has declared the technology secret. Nevertheless, it is possible to speculate on the engine on the basis of models and technical plans already released.

Slung beneath HOTOL's fuselage is a large engine inlet of a type closely associated with a conventional jet engine's rotating turbocompressor. One possible approach that this suggests is the cryojet. Such an engine relies on the liquid hydrogen fuel to chill aerodynamically heated air, entering the inlet at temperatures of hundreds or even thousands of degrees, down to approximately its natural outside temperature (but no farther, lest the engine become clogged with ice). Cooling increases the density of the air, so that a compact engine can produce the same thrust as a larger one. And it allows the engine to reach higher Mach numbers without running up against the temperature limits that restrict a turbojet's speed. Indeed, theoretical studies show that a cryojet can offer performance close to that of an air turbo-ramjet at speeds of Mach 4 or higher.

Some of the speculation over HOTOL's source of power may soon end; British Aerospace has promised a "significant release" of information later this year. But plenty of doubts will remain over funding for the ambitious craft. The British government plans to ask its partners in the European Space Agency to share the estimated bill of $7 billion for an operating HOTOL. So far, the other Europeans have shown little enthusiasm.

which the wings blend into the body. Its lift-to-drag ratio of more than 4 to 1 would enable an aerospace plane reentering the atmosphere to glide unpowered from Australia to California, and its blended-wing design would mean less dead weight in space.

The minimal wing surface need not compromise the plane's lifting ability. The scramjet engines will be slung in modules beneath the undersurface. Forward of these modules, the underbelly will act as part of the engines' inlets at hypersonic speed, channeling air to the engines while increasing its pressure. To the rear, the underbody will slope upward to act as part of the nozzle, allowing the exhaust to expand and produce more thrust. Lift will come from the increased pressures along the entire undersurface. A 200,000-pound aircraft with a 100-foot-long forebody could thus have a vertical force of 90,000 pounds on the forward undersurface and 95,000 pounds on the rear undersurface. The remaining lift would come from tilting the nose up slightly.

To raise the nose at takeoff, McDonnell Douglas plans to use retractable canards (small forward wings). Canards might also be used on the X-30, allowing it to take off at airliner-like speeds. Once the nose is up, the broad surface of the underside will produce enough lift for a takeoff. The wings might be reduced to small, vestigial surfaces, designed mainly for improved control at low speeds.

The search for an optimal shape—one that gives good performance at all speeds—will be just one of many challenges for the airframe designers. Another will be the integration of the aerospace plane's structural design, liquid-hydrogen tanks, and thermal protection. No one has ever built cryogenic tanks that can be reused for multiple missions into space. But protecting the structure from the extraordinary heat load that it will encounter presents a far tougher challenge. During a two-hour cruise in the atmosphere at hypersonic speeds, an aircraft will receive 1000 times as much total heat as the shuttle on its 12-minute glide down from orbit.

The shuttle uses the "cold-structure" approach. Its basic structure is simply that of an aluminum airplane. Overlaid on its skin are the thermal-protection tiles that have proved so costly and trouble-prone. The tiles' outside surfaces stand up to reentry heat, while their insulating interiors keep the heat from reaching the skin.

But this approach keeps the heat outside the vehicle, whereas scramjets above Mach 12 or so need to recover the heat and transfer it to the hydrogen fuel. This demands "hot-structure" design, with an outer skin insulated from the aircraft interior with its cargo, propellant, and crew. To accommodate stresses caused by accelerations, aerodynamic pressures, and thermal expansion, the skin must consist of small sections joined with metallic seals. The challenge is considerable; no hot structure has ever operated routinely at such elevated temperatures.

Nickel alloys fabricated in honeycombs and sandwiches represent the traditional choice of materials for hot structures, but they are heavy. Rapid-solidification titanium, fabricated the same way, will thus offer an attractive alternative.

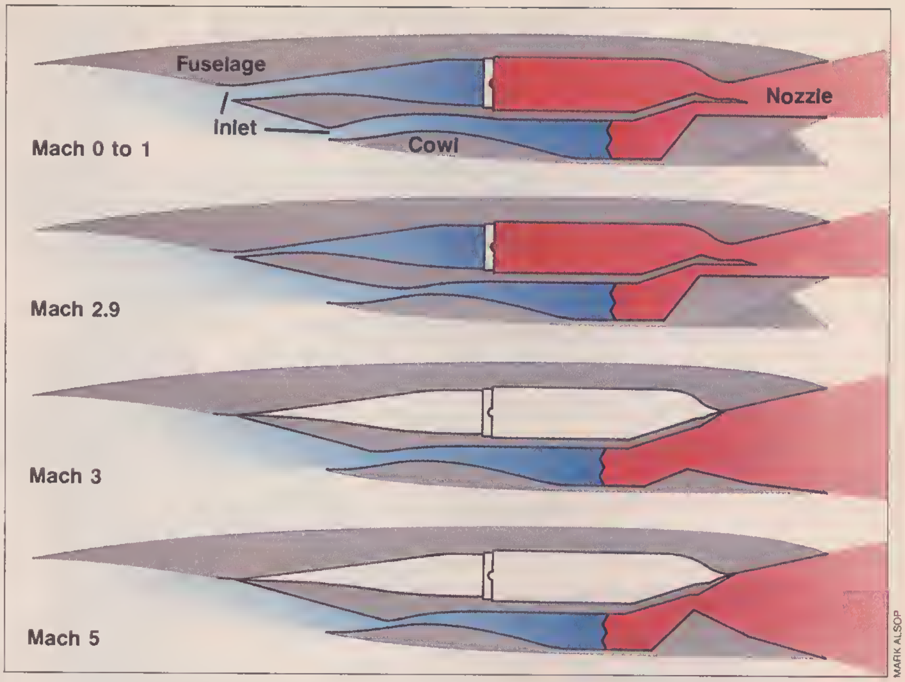
Even more conjectural are the heat exchangers that will transfer energy from the hot exterior to the fuel. Because hydrogen cools by convection rather than by conduction, it must flow

at high speed and pressure through large numbers of small tubes with a high surface area. This represents an open invitation to leaks. One concept thus proposes to rely on sodium, which cools through conduction, as the main heat exchange fluid. Pushed by electric pumps, sodium can flow at low speed and pressure through wider tubes. It can accommodate temporary surges of heat without burning through a tube. And its technology has been extensively developed in the nuclear industry.

The main question is whether the space plane will be able to return to the air soon after it lands. An approach that requires the servicing of multiple heat exchange loops would be difficult and risky. As a result, the quest for more elegant approaches will be a major part of the contract work on engine and airframe design over the next three years.

The five competing airframe companies will have their first showdown next June. Only two or three conceptual designs will qualify for the next round of contracts, worth $25 million apiece for 28 months of work. The winning companies will conduct major structural tests on key pieces of their concepts. In late 1989, the contractors will present preliminary designs ready for development, along with results from experimental tests to show that they have solved the most difficult problems in airframe construction and thermal protection. If everything is in order, the program will then leave DARPA. The X-30, aimed at proving technologies for ascent to orbit, will enter mainstream engineering development, under Air Force management.

The Defense Department may decide at that point to build a variant of the X-30, to explore the aerospace plane's other basic mission: long-duration hypersonic cruise. The two types of flight impose different kinds of heat load. While ascent causes short but very intense heating, cruise produces a thermal soaking, which may be modest in intensity but quite prolonged. The experimental-plane stage will be the best point at which to start developing two different forms of the aerospace plane.



◆ *NASA's concept for the aerospace plane involves variable-geometry air inlets, whose parts assume different positions as the plane's speed increases. This approach is necessary because airflow through inlets easily breaks down in supersonic flight.*

◆ *One possible shape devised by DARPA for the X-30 aerospace plane lacks conventional wings. Instead it will gain lift from increased pressures on its undersurface.*

As for the commercial market, McDonnell Douglas's chief scientist for the Orient Express, Paul Czysz, notes that any ascent-to-orbit aircraft will incorporate classified technology and thus will fall under export controls. His hypersonic airliner is therefore a "derated" version that will take advantage of the synergistic design principles used for orbital space planes but use less sophisticated technology. Air turboramjets will replace scramjets, heat exchangers will be unnecessary, and methane fuel—liquefied natural gas—will substitute for hydrogen. Since liquid methane is denser than hydrogen, it will allow the airframe to accommodate a large passenger cabin while still carrying enough fuel for hypersonic hops around the globe.

How feasible is the concept of a commercial aerospace plane? "By the turn of the century, well over 1000 wide-bodied jet liners will have seen decades of commercial service and will be ready for replacing," says John Swihart, a corporate vice-president at Boeing. But although "the technology could be right at that time for a Mach 3.3 airliner that could cross the Pacific in less than four hours," he says, "NASA and the Air Force will have to take the lead with even more advanced technologies if we are to move into the hypersonic realm." Wolfgang Demisch, an aerospace analyst at First Boston Corp. (New York), is more optimistic. "My assumption is that the technology can be made to work fairly readily in a timeframe of about 15 years for a hypersonic transport that will travel at about Mach 7," he declares. "Anything that transforms the Pacific trip from a prison in which you're nailed to a chair for 16 hours will be extremely well received." □

T. A. Heppenheimer, a freelance writer based in Fountain Valley, Cal., has a PhD in aerospace engineering.

For further information see **RESOURCES**, *p. 68.*


IBM®

SHARPENING YOUR VIDEO DISPLAY

Adapter boards for IBM PCs and clones can yield better resolution and color

Video displays have come a long way from the early days of microcomputers, when the high cost of parts forced compromises such as coarse graphics and upper-case letters only.

In 1981 IBM tried to resolve these problems by offering two video display alternatives, the Color Graphics Adapter (CGA) and the Monochrome Display Adapter (MDA). These remain the most widely used displays in IBM-class micros; most PCs and clones are sold with one or the other. Nevertheless, both adapters are now obsolete, and experienced buyers avoid them.

The CGA can drive low-cost video monitors derived from mass-produced television sets, but it produces images with very low resolution (640 × 200 pixels) in a severely limited range of colors. IBM's designers considered memory so expensive in 1980–81 that they didn't use enough to permit text scrolling without breaking up the video image.

Meanwhile, the MDA became the most common video display board, since its 720 × 350–pixel format produces far more legible text than the CGA. The MDA, however, could only display text, so many software developers decided not to use graphics in their programs, and thus we now have a large body of lackluster software for the IBM PC, including most of the best-selling packages.

Together, the CGA and MDA boards probably set graphics back two years or more, and the industry is still recovering. Many manufacturers such as NEC, Texas Instruments, and Tandy tried to sell non-IBM-compatible computers mainly on the basis of demonstrably better video displays. Yet IBM's early start, market presence, and momentum made its PC design the standard despite the problems.

Living in an IBM-dominated market, the independent board manufacturers built exact clones of the CGA and MDA, as well as video boards with special features. One class of boards (such as the Paradise Modular Graphics Card and the Everex Edge boards) put CGA images on the IBM monochrome CRT. CGA images and MDA monitors are so different, however, that the combination usually produces squashed images; adjusting image height on the monitor creates problems when switching back to normal MDA mode. Compaq's dual-mode screen display essentially follows this scheme with image height correction.

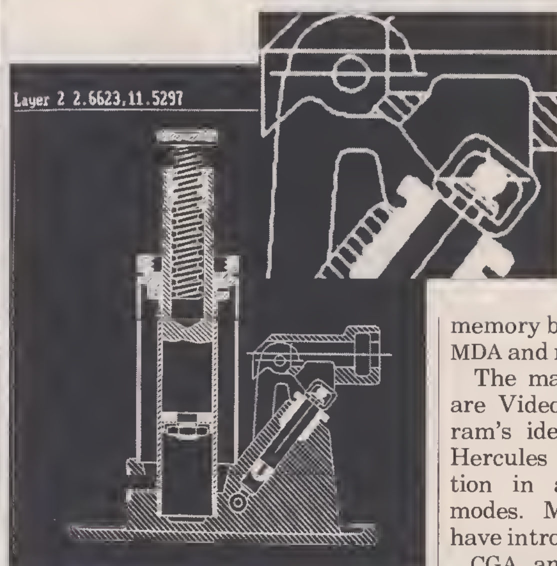
Other designs added features to the IBM boards while maintaining compatibility. Paradise and Everex produced boards that combined both CGA and MDA hardware and added enough memory to the CGA side to scroll images more smoothly. (But software developers in some cases had slowed down their programs to allow for poorer hardware.) Plantronics developed a CGA variant with more memory and thus more color choices; its design has attracted some software support and several hardware copycats.

Hercules developed the most important independent video board by putting bit-mapped graphics (720 × 348 pixels) on the IBM monochrome monitor while maintaining compatibility with the MDA. The Hercules Graphics Card (HGC) has drawn support from most important application programs and has been widely copied. If you buy an HGC clone, check carefully: construction quality varies widely. On a PC/AT or equivalent, Classic's High Speed Monochrome Graphics Adapter works up to 20% faster because it connects via a 16-bit bus; other HGC boards use the older 8-bit bus. The standard character set used by Classic is not quite as good as the MDA/HGC characters, however, and programs that blank the screen after inactivity (to save wear on the monitor) do not work correctly.

For improved color images, IBM brought out its Enhanced Graphics Adapter (EGA) in 1985; its 640 × 350–pixel image finally established a color image standard of acceptable quality. Software support for the EGA is growing, and most important programs should support it by the end of the year. For full function, EGA boards need 256 kilobytes of on-board memory. To get this memory, the IBM EGA card requires expensive add-on accessories; nearly all of the many cheaper EGA-clone cards come with the memory built in. All EGA boards serve MDA and most CGA functions as well.

The market leaders in EGA clones are Video-7's Vega board and Quadram's identical QuadEGA; they add Hercules images by software emulation in addition to standard EGA modes. Many other manufacturers have introduced similar boards.

CGA and HGC operation on EGA boards leads to occasional problems. In most cases, the CGA and HGC format is emulated through software, and in some cases an applications program will assume some specific CGA or HGC



The 1280 × 800–pixel Wyse WY-700 display is among the highest-resolution packages for micros. The inset (shown at actual size) demonstrates the detail possible.

by Cary Lu

Choosing a monitor

In the profusion of computer monitors currently on the market, several products stand out. For monochrome, the Princeton Graphics Max-12 works well with both Hercules and CGA images and is much more sturdy than the fragile IBM monochrome monitor, which can be easily damaged by simple connection errors and even some software.

For monochrome CAD software, reversed (black-on-white) images can be easier on the eyes than the usual green or amber on black. The Roland MB-142 costs more than other monochrome monitors, but it has a white phosphor and an image-reversing switch. When reversed, the white phosphor image flickers a little and text characters bleed into the black border. If you buy a Roland monitor, make sure it will display all 720 pixels horizontally across a Hercules image; some samples shave off a few pixels.

The NEC MultiSync monitor is a clear leader among the color models. Not only does it create a fine image, but its circuits can adjust to all the common scanning frequencies, from CGA to EGA to PGA and more, up to 800 × 560 pixels. Other monitor manufacturers have been hurrying to catch up; a half-dozen similar monitors should be available by fall. Inspect the monitors carefully—many models fail to achieve accurate convergence (white characters in the corners should be crisp and free of color fringing).

hardware that is missing from the board. The CGA problems occur only in a few earlier programs, most of which have been revised, and in some games. If you have these problems, the Vutek EGA board has exact CGA hardware equivalence. Similarly, when running in Hercules mode, some programs expect a 6845 graphics controller chip, which is not used on standard EGA cards. Genoa has announced that its new SuperEGA card will include the chip for exact Hercules functions; Paradise also plans hardware emulation.

Anyone buying an IBM PC–class computer now should consider only Hercules or EGA video displays and software that supports such displays. For monochrome images, Hercules and EGA (in monochrome mode) are about equivalent, and the EGA is catching up rapidly in software support. For color, the EGA is the only practical choice. Overall, monochrome displays are still sharper and less fatiguing to the eyes, so Hercules or EGA monochrome remains the best choice, despite the attractions of EGA color.

Since video hardware is no more useful than the quantity of compatible software, most of the other video adapters can offer only limited utility. Many companies, including AT&T and Hewlett-Packard, have produced video adapters for their PC clones with modestly better images than the EGA, usually 640 × 400–pixels. Unfortunately, most software simply treats these as 200-line displays; the board doubles the pixels vertically to make up 400 lines. A few products offer both improved resolution and backwards compatibility. The Wyse WY-700 monochrome video board and monitor boasts 1280 × 800–pixel resolution with CGA and MDA emulation, and is available with a Microsoft Windows driver. Although its $1600 list price inhibits quick sales now, such high resolution will be common in the future. NEC's Power Graphics Board offers 1120 × 750–pixel resolution in color and EGA compatibility; the list price for a complete system (boards and monitor) is $3015.

Only computer-aided design software is commonly modified for the many other expensive, higher-resolution boards on the market such as the IBM Professional Graphics Adapter (PGA). Graphics standards will help this situation greatly, freeing software developers from the chore of customizing their programs for each hardware variation. Instead, software need only send out display instructions in a standardized form called graphics primitives; interchangeable drivers for the specific display hardware will interpret the instructions to create the image.

In addition to better resolution and graphics standards, future video boards will come with their own processors. A dedicated graphics processor takes a computing load off the main central processing unit and speeds up the display. The leading graphics chip contenders are the Texas Instruments (TI) 34010 and the Intel 82786. Both include hardware for fast manipulation of bit-mapped images on screen—up to 25 times faster than current video boards. And both can also handle other graphics devices such as laser printers. The TI chip is essentially a general-purpose 32-bit processor with imaging functions. It does not use graphics primitives, relying instead on software drivers to create algorithms for drawing images. The Intel chip has less general processing power but does have graphics primitives for drawing lines, rectangles, arcs, and polygons.

Video boards incorporating these chips should appear by the end of this year and go into wide distribution in 1987. They will likely run older video modes for software compatibility; but with software designed to take advantage of the chips, we'll all wonder how we managed to live with the crude video displays of the mid-1980s. □

Cary Lu is microcomputer editor of HIGH TECHNOLOGY.

Companies

Classic Technology, 2090 Concourse Dr., San Jose, CA 95131, (408) 434–9333
Everex Systems, 891 Maude Ave., Mountain View, CA 94043, (415) 967–1495
Genoa Systems, 73 E. Trimble Rd., San Jose, CA 95131, (408) 945–9720
Hercules Computer Technology, 2550 Ninth St., Berkeley, CA 94710, (415) 540–6000
NEC Home Electronics (MultiSync monitor), 1401 Estes Ave., Elk Grove Village, IL 60007, (312) 228–5900
NEC Information Systems (Power Graphics Board), 1414 Massachusetts Ave., Boxborough, MA 01719, (617) 264–8000
Paradise Systems, 217 East Grand Ave., South San Francisco, CA 94080, (415) 588–6000
Princeton Graphics, 1101-1 State Rd., Princeton, NJ 08540, (609) 683–1660
Quadram, 4355 International Blvd., Norcross, GA 30093, (404) 923–6666
Roland U.S., 7200 Dominion Circle, Los Angeles, CA 90040, (213) 685–5141
Video-7 (Vega), 550 Sycamore Dr., Milpitas, CA 95035, (408) 943–0101
Vutek Systems, 10855 Sorrento Valley Rd., San Diego, CA 92121, (619) 587–2800
Wyse Technology, 3571 N. First St., San Jose, CA 95134, (408) 433–1000

LASERS TO BRIDGE SATELLITES

Secure links with high capacity may appear in the '90s

Laser communications systems, having begun to revolutionize long-distance data transmission on earth, are now moving into space. Whereas terrestrial fiber optic networks send pulses of laser light down hair-thin fibers of glass or plastic, future satellites will exchange information by transmitting modulated laser beams across thousands of miles of empty space. Such laser intersatellite-link (ISL) systems, currently under development in West Germany, France, and the U.S., could be deployed on satellites by the early 1990s.

Laser ISL technology is a cousin of microwave intersatellite communications. Information can be imposed on a beam of laser light in much the same way that it is modulated onto a millimeter radio wave. And just as a microwave intersatellite link transmits signals with a directional parabolic antenna, a laser ISL system will use an optical telescope to concentrate and aim the beam of light. At the target satellite, a receiving telescope—analogous to a microwave receiving antenna—will capture the diffuse laser signal, concentrate it, and focus it onto a detector.

The major application of laser ISL technology will be to cross-link military satellites in geostationary orbits at 22,300 miles altitude so that they can communicate without having to rely on vulnerable ground stations or dedicated relay satellites. In addition, the Strategic Defense Initiative (SDI) Organization regards laser links as essential for its envisioned network of satellites carrying surveillance sensors, weapons, and supercomputers, which will have to exchange vast amounts of intelligence and targeting data extremely rapidly.

Laser ISL offers a number of advantages over conventional microwave systems. Optical frequencies fall outside the crowded radio-frequency bands used for most satellite communications. And because the frequency of laser light is much higher than that of microwaves, its information-carrying capacity is an order of magnitude greater. Indeed, ground-based laser communications systems have transmitted more than 1 gigabit (a billion bits) of data per second—the equivalent of about 100 color TV channels.

Another major advantage stems from the fact that the wavelength (and thus the divergence) of laser light is much less than that of microwaves. Hence, a laser intersatellite link can use a smaller reflector to transmit a narrow beam. A laser ISL transmitter would require a telescope mirror less than a foot in diameter, whereas the parabolic reflector of a 60-gigahertz microwave antenna would be nearly 10 feet in diameter. The compactness of laser ISL systems should enable designers to significantly reduce the overall size and weight of satellites.

Finally, the small divergence of laser light means that the beam remains narrow over great distances, spreading to a diameter of only about 1 kilometer at a distance of 50,000 kilometers. By reducing energy loss at the receiver, the narrow beam permits use of a relatively low-power transmitting laser. And because clear reception of the laser signal is possible only when a receiver is located near the center of the beam, laser intersatellite links are highly resistant to jamming and interception. They are also unaffected by electromagnetic pulse, an indirect effect of nuclear explosions that disrupts microwave communications.

Before two satellites can communicate optically, the receiving satellite must acquire the laser signal from the transmitting satellite with an accuracy of less than a beam-width. If the transmitting telescope knows the approximate location of the receiving satellite, it can defocus the beam until it contacts the target satellite (see diagram). Otherwise, the transmitting telescope must shoot out beams in all directions until it acquires and locks onto the receiving satellite—a process that takes several seconds. Then a spatial tracking loop keeps the transmitter trained precisely on the receiver. Such dynamic tracking is essential if the two satellites are moving with respect to each other.

The choice of laser system is critical. Military and civilian laboratories are pursuing two complementary approaches: carbon dioxide lasers for long-distance communications, and compact, low-power semiconductor lasers for shorter distances.

CO_2 laser technology is well developed and provides enough laser power for long-haul messages. The Battelle Research Institute (Frankfurt, West Germany) is developing a carbon dioxide laser for space communications over distances of 45,000 miles or more, making it capable of linking satellites in low earth orbit with geostationary satellites. Known as Inter-Satellite Laser Links (ISL2), the space-qualified version is expected to weigh about 80 pounds. In experiments funded by the European Space Agency and the German Ministry of Research and Development, the Battelle researchers have demonstrated a data transmission rate of 1 gigabit per second, and they expect to achieve capacities of up to 5 gigabits per second. The group plans to develop a working laboratory model by 1987 and a flight-test model by 1991. If all goes well, ISL2 could be deployed on a working satellite by about 1995.

Semiconductor diode lasers generate less powerful beams than do gas lasers, but their smaller size and lower power consumption make them more efficient for intersatellite communications over shorter distances—between adjacent satellites in geostationary orbit, for example. CNES, the French national space agency, is working on an ISL system based on diode lasers. In the past, such lasers have been noisy, and their frequencies have been unstable. But recent advances have made it possible to manufacture gallium-aluminum-arsenide (GaAlAs) semiconductor lasers that emit a continuous beam of highly coherent light, consisting almost entirely of a single, pure wavelength. The frequency varies by about 10 megahertz—less than one part in 10 million. And with precise control of

by Jonathan B. Tucker

HATCHED IN FLORIDA.

High tech was hatched in Florida. On January 31, 1958, when a Jupiter rocket put Explorer I into orbit.

Almost three decades later, we're the leading high-tech state in the Southeast, in terms of employees and number of firms.

Florida is a national leader in the manufacturing of personal computers, telecommunications equipment and medical instruments.

Florida's work force is reliable, loyal and well trained.

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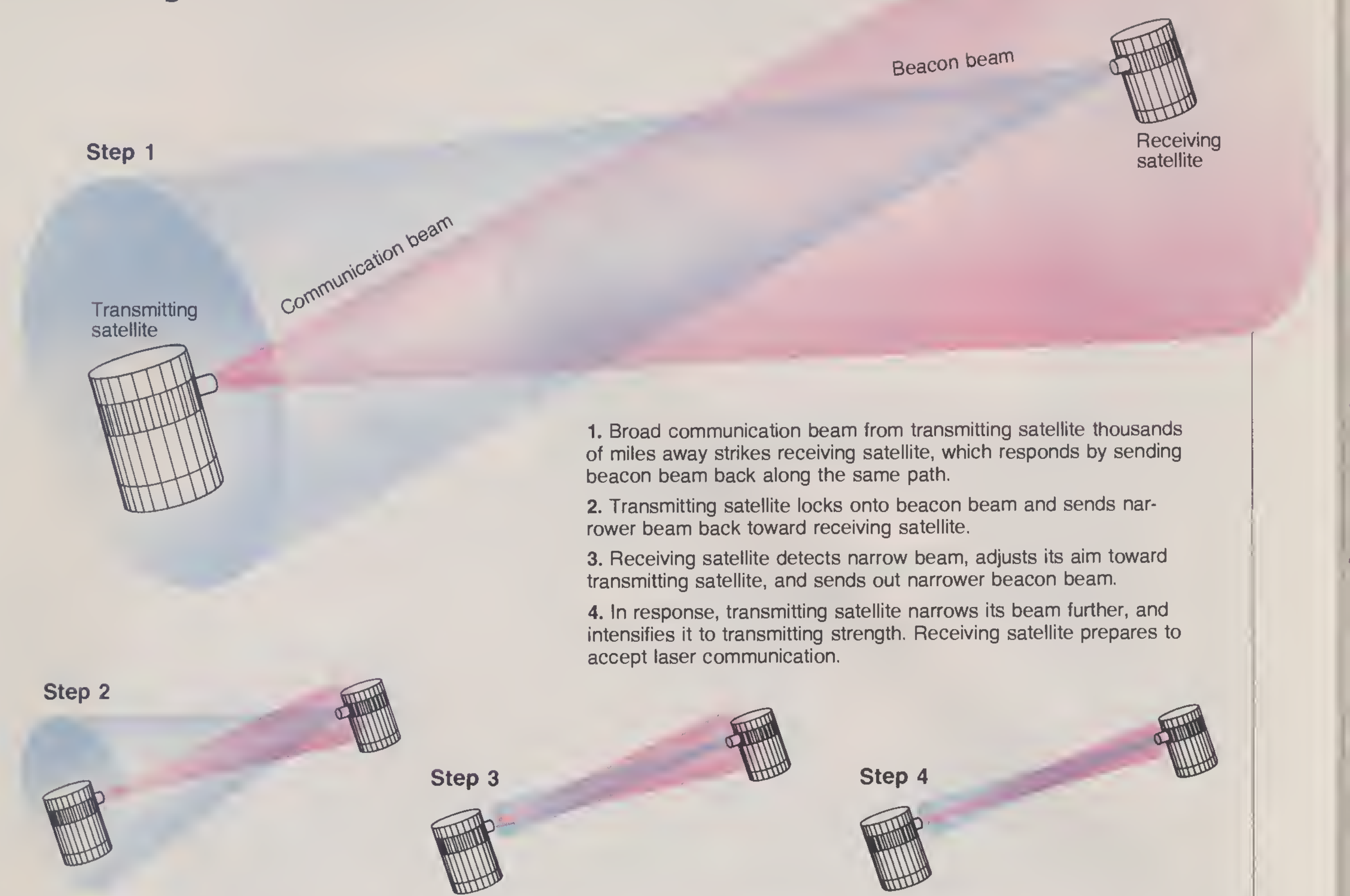
Establishing a laser link



1. Broad communication beam from transmitting satellite thousands of miles away strikes receiving satellite, which responds by sending beacon beam back along the same path.

2. Transmitting satellite locks onto beacon beam and sends narrower beam back toward receiving satellite.

3. Receiving satellite detects narrow beam, adjusts its aim toward transmitting satellite, and sends out narrower beacon beam.

4. In response, transmitting satellite narrows its beam further, and intensifies it to transmitting strength. Receiving satellite prepares to accept laser communication.

DAVE HANNUM

temperature and current, the frequency remains stable over time.

MIT's Lincoln Laboratory (Lexington, Mass.) is developing a prototype space laser communications system known as the Lasercom Package. Developed under contract from the Air Force Systems Command, the Lasercom system uses a small and relatively rugged and efficient GaAlAs semiconductor laser designed to last more than 10 years in space. Because the geometry of semiconductor lasers produces an elliptical rather than a circularly symmetrical beam, an optical system must circularize it so that it can be coupled efficiently to the transmitting telescope. Although the beam's power scarcely exceeds that of a flashlight, its divergence is so small that it can transmit moderately high data rates—on the order of 250 megabits (Mb) per second—thousands of miles through the vacuum of space.

Semiconductor lasers have another useful characteristic: the frequency of their light is sensitive to slight changes in the current passing through them. As a result, increasing or decreasing the current in small steps induces discrete shifts in the frequency of the emitted laser light. This effect provides a simple mechanism for internally modulating the continuous stream of light to carry information.

The Lasercom Package uses a type of modulation known as frequency-shift keying (FSK). This method encodes data by inducing small shifts in the frequency of the continuous laser beam. In binary FSK, for example, the internal modulator represents a binary *1* by inducing a slight shift in the laser frequency over a clocked time interval, and a binary *0* by leaving the frequency unchanged. FSK can also use higher-level alphabets, with 4, 8, 16, or 32 frequency shifts. Since the higher-level alphabets use fewer frequency shifts to specify a piece of data, the average power required to transmit data at a given rate decreases as the symbol size increases; thus the best performance can be obtained by using the largest symbol size permitted by the laser's bandwidth—the range of frequencies over which it can be modulated. For the Lasercom Package, octonary FSK (which uses sets of eight) works best.

The package also represents the state of the art in receiving and decoding the modulated laser light. Until recently, semiconductor lasers were limited to incoherent, or direct, detection, in which a photodetector converts the pulses of laser light striking it into a string of electronic bits. Although direct detection is a mature technology, its sensitivity is limited by background noise—from the sun in the receiver's field of view, for example—and thermal noise in the photodetector. Recently, however, the advent of narrow-spectrum semiconductor lasers has made possible a more sophisticated technique known as heterodyne detection.

Much like a conventional radio tuner, a heterodyne laser receiver contains a local oscillator that can be tuned to mix selectively with the incoming lightwaves. In the Lasercom Package, the local oscillator is a narrow-spectrum laser that emits a very pure optical wavelength. The incoming laser signal (at frequency A, say) combines with the local-oscillator laser

(at frequency B) on the surface of a photodetector, giving rise to an electric current that oscillates at the "beat" frequency (frequency B minus frequency A). This frequency mixing converts the incoming laser light into an electronic signal with a number of discrete channels that can then be amplified, demodulated, and decoded to extract the data. A frequency-tracking feedback loop detects fluctuations in the incoming laser light and corrects the frequency of the local-oscillator laser to adjust for them.

Because an optical filter in front of the detector screens out all frequencies except the extremely narrow range emitted by the laser, heterodyne detection is largely immune to background noise. Moreover, says Jeffrey H. Shapiro, professor of electrical engineering at MIT, the coherent nature of heterodyne detection makes additional processing possible. Thus, electronic filtering extracts the information imposed onto the laser beam by frequency-shift keying. These small frequency shifts, which are retained in the electronic signal, can be demodulated with a matched-filter receiver—a set of very-narrow-band electronic filters that detect the presence or absence of energy in each frequency slot over time. Demodulating an octonary FSK message, for example, requires a receiver with eight matched filters. In this way, the modulated beam of light is converted into an electronic stream of binary digits, which are then decoded and processed by a computer aboard the satellite.

Lasercom engineers at Lincoln Lab contend that heterodyne detection offers important advantages for space laser communications. Because heterodyne detection is largely immune to thermal and internal noises in the photodetector, it is 10 to 100 times more sensitive than direct detection at GaAlAs laser wavelengths. This enhanced sensitivity reduces by a factor of 10 both the power requirement of the transmitting laser and the aperture (diameter) of the telescope needed to detect the incoming beam, says Barney Reiffen, director of Lincoln Lab's Communications Division.

Laboratory prototypes of the Lasercom Package that use heterodyne detection, frequency-shift keying, and frequency tracking have operated at a data rate of more than 225 Mb per second. Now, Lincoln Lab engineers are building hardware prototypes of the system for flight testing on NASA's Advanced Communications Technology Satellite, to be launched in a few years. According to *Air Force* magazine, the laser package will be tested in two stages: phase I will demonstrate communication between Lasercom and a ground site, to verify the hardware, and phase II will demonstrate space-to-space communications. Once the technology has been proven, Lincoln Lab will transfer it to an industrial contractor for further development.

Several challenging problems associated with laser intersatellite communications remain. First, very high data rates may exceed the real-time processing capability of decoders small enough and light enough to fit on a satellite. Until improved decoders come along, the raw data might be stored in memory and then processed more slowly. Or individual satellites might be used simply as "intelligent repeaters," relaying data by demodulating the incoming laser signal into an electronic bit-stream and then remodulating the stream onto an outgoing laser beam for transmission to the next satellite in the network. The data would ultimately be transmitted down to a ground station for decoding.

But getting large quantities of data from satellites down to earth also presents major difficulties. Since radio-frequency downlinks have very limited capacity, it may be necessary to compress the data with extensive on-board processing before transmission to the ground. Alternatively, the data might be stored in memory and transmitted to earth during quiet periods. Eventually, lasers themselves may provide space-to-ground links. That will require several ground stations in desert locations, to ensure that at least one is cloud-free at any given time. Presumably, an orbiting satellite will determine whether the atmosphere over a particular site is clear enough for optical transmissions by detecting a beacon from a ground station below.

Assuming that it goes ahead, SDI will provide the ultimate challenge for space laser communications. First, it will require reliable transmissions at data rates in excess of 1 gigabit per second, necessitating higher-power lasers. Second, the bright earth, rather than the blackness of space, may provide the background to the laser signal, greatly reducing the signal-to-noise ratio. Third, because the SDI satellites will be moving continuously relative to one another and to the earth's surface, they will have to acquire and exchange laser-ISL signals extremely fast. Fourth, the network will have to be reconfigurable, so that it will still operate even if several satellites are destroyed. Finally, the laser ISL system must be highly reliable: if for some reason the satellites cannot communicate, the entire SDI system will fail to operate.

Because these requirements far outstrip the state of the art, the SDI Organization's Innovative Science and Technology Office (IST) is sponsoring an ambitious research program on laser satellite networking technology. A key objective is to develop narrow-spectrum semiconductor lasers with much higher power outputs than currently available. "If we can get lasers with both high powers and high coherency, then it will be possible to use heterodyne detection," says Kepi Wu, an engineer who manages IST's Laser Crosslinks and Networking program. "Otherwise, we are prepared to develop a system that would use noncoherent detection," at the cost of some loss in sensitivity.

In fiscal 1986, IST will grant five research contracts to university and industry groups to work on laser ISL concepts and devices, according to Barry Hughes, head of the Advanced Concepts and Engineering Division at the Space and Naval Warfare Systems Command (Crystal City, Va.). The contracts will last three years and should provide the basis for assessing whether SDI's challenging requirements for laser ISL are technically feasible.

Space laser communications systems should eventually find civilian applications as well. NASA is interested in laser ISL technology to satisfy its projected need for a 700-Mb-per-second transmission capability by the end of the decade, and at least a 1-gigabit-per-second capacity by the year 2000. For example, earth-resources satellites in low orbit can easily generate more than 1 gigabit of data per second, which could be sent via laser to a dedicated relay satellite for storage and later transmission to earth. Laser communications may also move into the commercial satellite market. "Lasercom is useful for all kinds of applications in which satellites have to talk to other satellites," says Lincoln Lab's Reiffen. "In the commercial context, you can imagine cross-linked satellites communicating from any point on earth to any other point without going through ground relays." □

Jonathan B. Tucker is a former senior editor of HIGH TECHNOLOGY.

CELLULAR SYSTEMS EASE MOBILE PHONE WOES

Automotive use is expanding fast, and the age of pocket phones may not be far off

Traditional mobile phones win no awards for being there when you need them. Because 20 channels typically are shared by some 2000 subscribers, there are times when you can't get a connection, or even a dial tone. But this situation is changing: "cellular" telephone systems—in which cities are divided into many cells, each with its own antenna—are now providing subscribers with reliable mobile phone service of a quality equal to that of wired telephone systems.

Two years after the first U.S. cellular system started commercial service, 38,000 cellular phones are operating in Chicago. In Los Angeles, the system is already overloaded, with 50,000 subscribers. So far, more than 90 U.S. cities have some type of cellular service.

Demand is exceeding expectations by 20–30%, says Robert W. Mayer, executive director of the Cellular Telecommunications Industry Association (Washington, D.C.). In the last six months of 1985, the number of subscribers doubled on virtually all established systems, he says. Brian Wood, director of corporate communications for Bell Atlantic Mobile Systems (Basking Ridge, N.J.), estimates that there will be 1.5 to 2 million subscribers nationwide by 1990. And Charla Hewitt, manager of marketing development for Contel Cellular (Atlanta), says "the industry is expecting that by 1990 this will be a $6-billion-a-year business."

While most observers agree that cellular has the potential to become a mass-market utility, not all are quite as optimistic as Wood and Hewitt. A report on the cellular industry by market research firm Business Communications (Stamford, Conn.) predicts that by 1993 there will be some 1.3 million cellular subscribers who will generate $967 million in annual service revenues and $532 million in annual phone sales.

Not surprisingly, many of the initial users of cellular phones are those who previously used traditional mobile phones—senior executives and people in direct sales, real estate, and construction. But the technology appeals to a broader market and lends itself to a variety of creative uses. "One of our more unusual customers is a Chattanooga radio station that uses a briefcase phone [with a telephone and battery pack in a briefcase] for live broadcast of high school football and baseball games," says Randy Harber of Bell South Mobility (Atlanta). "At each game, their sports commentator is on for about 90 minutes. That costs $36, or 40¢ a minute. By comparison, installing a wired phone at a stadium for a day to allow a broadcast costs $140. The station saved its initial investment in the $2995 briefcase phone in the first season."

The *Atlanta Journal–Constitution,* Georgia's leading daily newspaper, has gone a step farther, based on cellular systems' ability to transmit data as well as voice. The paper has equipped its sports department with a briefcase that contains a lap-top computer as well as a cellular phone and modem. Sportswriters take the briefcase to games, compose their stories, and send them to the newspaper from the stadium.

Future applications might include remote troubleshooting. Your auto mechanic, for example, could use cellular diagnostic equipment to remotely poll your car's onboard computers and identify the cause of a problem. "Most people think of cellular as a car phone, but in the very near future we will see much more," says Larry Harris, director of network operations at Cellular One (Schaumburg, Ill.). "Cellular pay phones will appear in cabs, buses, and trains. Burglar alarm systems will also use cellular. When burglars defeat alarm systems, 90% of the time they do it by cutting the telephone wire. Cellular eliminates the wire."

Such applications are being fueled by technological advances in such areas as microprocessors and batteries

Cellular transmission systems are best known for their ability to support large numbers of mobile telephones. But, as illustrated by BellSouth Mobility's Cellular Link products, the systems can also carry data from portable computers, facsimile transmissions, and voice for radio broadcasts.

by G. Berton Latamore

that are rendering cellular phones smaller, less expensive, and in some cases, portable. Phone prices dropped 50% in 1985, for example, and are expected to continue decreasing, although not as sharply. Mobil phones are currently priced in the $1500–$2500 range. "Right now the lowest price you'll find for cellular phones in most markets is about $900," says Mikal Thomsen, operations manager for McCaw Communications (Bellevue, Wash.). "We believe that will drop by $200 this year."

In 10 years, Thomsen predicts, "cellular will compete with wire-line service, and 5% of the U.S. population will have cellular phones. When people want new phones, they may choose a cellular phone they can carry with them instead of a wired phone for their living rooms."

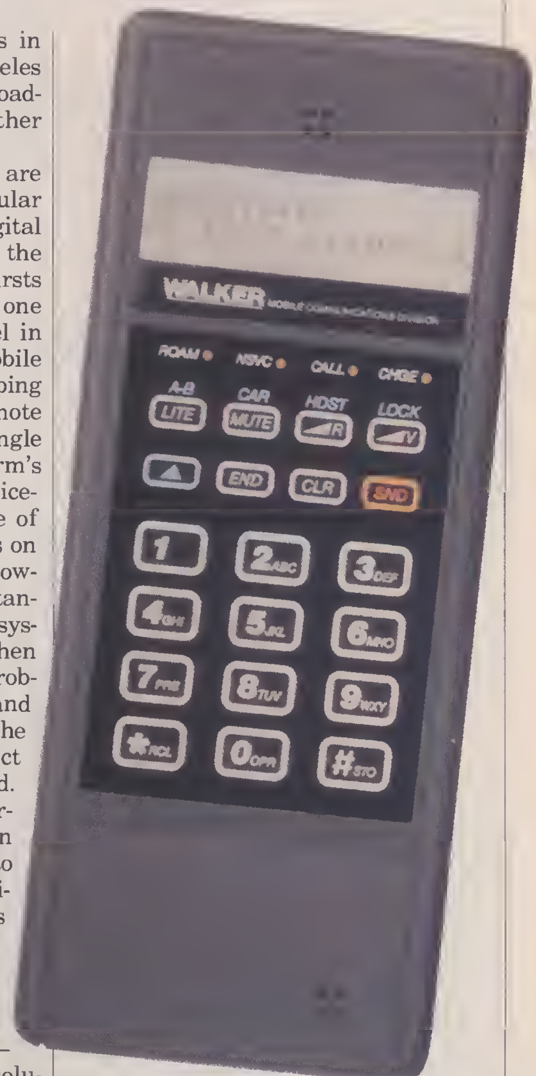
Cellular systems are providing subscribers with reliable mobile phone service of a quality equal to that of wired telephone systems.

For this scenario to materialize, cellular systems must further expand the number of users they can support. In Los Angeles, the limits of present cellular technology are already being felt. Pacific Bell, the only cellular service operator in the region, hasn't been able to shrink cell sizes fast enough to keep up with demand. A second company, Los Angeles Cellular Telephone, has a license to begin operating a competing system this summer, but even after it starts operations and doubles the number of available channels, problems may continue.

"We expect the L.A. scenario to happen in many cities," says Thomsen. "You just can't shrink the cells small enough to serve everyone when demand is too high. The customers in New York, Chicago, and Los Angeles are experiencing the kinds of overloading problems today that users in other markets will face in five years."

Fortunately, new technologies are being developed to increase cellular capacity. The most promising is digital transmission, which can exploit the brief pauses that exist between bursts of binary code to carry more than one conversation on the same channel in the same cell. International Mobile Machines (Philadelphia) is developing digital broadcast phones for remote sites that allow four users on a single channel. George Calhoun, the firm's technical VP, maintains that voice-coding technology is on the verge of allowing eight or 16 conversations on a channel. Before that happens, however, the industry must agree to standards so that users of one digital system can talk over their phones when in other areas. Also, technical problems concerning synchronizing and routing transmissions—so that the correct phone receives the correct bursts of data—must be solved. Such synchronization is particularly tricky during the handoff (when the signal is passed from one cell to another) and is exacerbated by digital's ability to support several calls on each channel.

Digital systems also have the drawback of requiring system operators to replace much of their existing transmission equipment—a sizable investment. An interim solution for some operators may be the use of a signal modulation technique called amplitude compandered side band (ACSB), which splits the available frequency range into more channels to allow more conversations at once. This is achieved by compressing the dynamic range of each signal's amplitude prior to transmission, thereby permitting more signals to be squeezed into a given band of the spectrum; the amplitudes are then expanded at the receiving end. ACSB is easier and less expensive to retrofit onto existing analog systems than is digital, and is therefore attractive to current system owners. These owners may wait until their analog equipment has had a chance to fully depreciate before making the switch to digital, leaving it to new system operators to first bring digital cellular to market.



Walker Communications' 15-ounce, battery-powered portable phone has a limited range, but it may be the first of a new generation of personal phones.

Another problem facing the cellular industry is spotty coverage. Cellular systems carry high fixed costs—for switches, transmitters, and other hardware—that must ultimately be borne by users. Thus the fewer users on a system, the higher the price of individual service. As a result, cellular systems that are potential gold mines in major urban areas may not be eco-

Strong service with weak signals

How can cellular technology serve thousands of callers within each city when traditional mobile technology allows only 20 people to talk at a time on each system?

The basic limit of radio communications is the width of the transmission spectrum. The usable spectrum supports only a limited number of channels, which can quickly be filled with calls. A traditional radio telephone system uses a single central communications antenna for all telephones on the system. The amount of spectrum allocated for this kind of radio telephone supports about 20 channels, allowing 20 people to talk at once. All other callers must wait until one of those 20 hangs up.

Cellular telephone employs much weaker signals and multiple antennas, each serving a limited geographic area—a cell. Thus two people in adjacent cells can use the same frequency band for their calls. A system with 50 cells could carry 50 simultaneous calls on one channel. In addition to its more efficient use of each channel, cellular has more channels available to it than traditional mobile phone systems, since it has been allocated a larger frequency spectrum by the FCC. When a cellular system becomes overloaded, the cells can be split, say, by installing extra transmitters to divide the overloaded cells in two.

Users are not forced to stay in a single cell while making a call. When a cellular phone moves from one cell to another, a computer at the central switching site tracks the movement and automatically transfers the call to the new cell's transmitter without any service interruption. If the calling frequency in the new cell is already occupied, the computer shifts the call to a new frequency. (If all the new cell's channels are occupied, however, the call could be lost.)

Cellular even allows users to wander outside their normal service area and still get calls. Nearly all of the Northeast Corridor now has cellular service, for instance, and a subscriber driving from Boston to Washington, D.C., can make and receive calls virtually anywhere along the way. Similarly, New York subscribers can use their phones in Chicago or Los Angeles.

nomically viable in small markets or in the vast stretches of rural America. If you drive from New York to Chicago, for instance, your cellular telephone might be useless for most of the trip.

The coverage problem, however, hasn't seriously dampened metropolitan customers' demand for cellular phones, as illustrated by the growing number of subscribers in large cities. And according to most industry participants, this demand will increase further as pocket-size portable phones reach the market. One such phone from Walker Communications (New York) weighs just 15 ounces, looks like a large calculator, and is totally portable. At $3295, the phone is expensive, and battery limitations allow it to produce only 0.6 watt of power, giving it less range than 5-watt automobile phones. It runs for half an hour and provides eight hours of standby time on a single battery charge.

Despite its limitations, the Walker phone may represent the first in a new generation of personal phones. Costs should drop as production volumes increase, and performance should improve with the advent of new battery technologies, industry observers predict. The resulting fully functional pocket-size phone might plug into a car or home unit for standard operation and recharging, but could be unplugged and carried anywhere the user traveled.

Ultimately, according to some predictions, every American will be given a personal phone number just like a personal Social Security number. People will keep their number for life, regardless of where they move, and will carry their personal phones with them always. When someone wants to talk to you, they will be able to reach you regardless of whether you happen to be at work, flying across the ocean, or window-shopping on Fifth Avenue. Of course, portable phones will also need a privacy switch so you can turn them off when you want some peace. □

G. Berton Latamore, based in Burlington, Vt., is editor of VideoPrint, *a newsletter on electronic publishing.*

BAR CODES KEEP FACTORIES ON TRACK

Those little black stripes are now doing for industry what they did for the corner deli

For more than 15 years, bar code scanning has been limited primarily to inventory management and supermarket checkouts. But now, aided by emerging standards, the technology is making inroads on the factory floor. Because it provides an "eye" for the computer controlling manufacturing operations, bar code scanning allows automated factory systems to keep track of materials and components. And since these data are stored in digital form, they can be used by other computers both inside and outside the company.

All bar codes use the same operating principles. The bar code itself is a strip of alternating black bars and white spaces, each usually of two different widths, which are arranged to correspond to binary digits that represent letters, numbers, or other symbols. Printed on adhesive-backed labels or directly on packages, the codes identify a product and provide such information as its color, expiration date, batch number, origin, and, if the label is attached to a box or shipping container, the number of units it contains.

A scanner consists of an illuminator—either a laser, a light-emitting diode (LED), or an incandescent bulb—a photodetector, and a microcomputer. The light beam directed at a code is reflected back by the white spaces between bars; the photodetector generates voltages corresponding to the relative intensity of each reflected element, and this analog signal is converted to digital form for analysis by the micro. Such data may then be transferred, of course, to other computers in the manufacturing system.

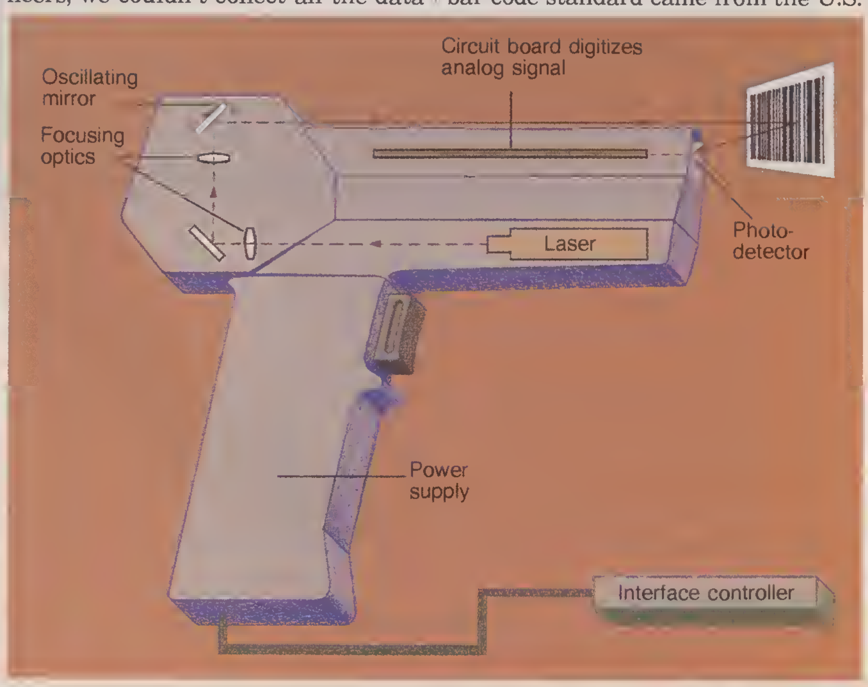
Bar code identification lends itself to a wide variety of manufacturing applications. For example, at Xerox's Electronics Division in El Segundo, Cal., a computerized tracking system called Equinox relies on bar codes to compile histories of individual printed circuit boards. Supplied by Intermec (Lynwood, Wash.), the system incorporates lightpen wands that allow workers to scan the bar code label identifying each in-process circuit board when it arrives at a workstation; the worker also scans separate codes identifying himself and the station. The Equinox host computer first determines if the product is in the right place; it may then provide the station operator with instructions tailored to the individual board, or it may ask the worker to enter data that go into the component's history. When manufacturing is complete, Equinox has a detailed computer file on each board that reveals what operations were performed, when, and by whom.

"Equinox is oriented toward identifying problems," explains Joseph M. Camarata, Xerox's manager of engineering/manufacturing processes. "We've made major improvements in quality, and we're getting paybacks. If we had a hundred industrial engineers, we couldn't collect all the data that system generates."

At General Motors' Buick plant in Flint, Mich., much of the just-in-time inventory delivery relies on bar code identification. In one case, a robot unloading car seats from delivery trucks scans bar codes to ensure that the seats are fed into the assembly line in the right sequence—thus keeping green seats out of red interiors. "With bar codes, we can be certain that each vehicle has the right transmission, each engine the right carburetor," says GM's Robert D. LaMoreaux, head of bar code coordination. "We're now scanning as many as two dozen bar codes on a newly assembled automobile."

With such growing reliance on bar codes, manufacturers are demanding that their suppliers send shipments coded in standardized language formats; a labeled product does little good, after all, if its recipient's equipment cannot decipher the code.

The precedent for standardization was set in 1974, when the National Association of Food Chains established the Universal Product Code (UPC) for grocery labels. Currently about 37% of U.S. food stores are equipped with scanning checkouts. In industry, the first, and so far the most significant, bar code standard came from the U.S.



ALAN WITSCHONKE

by Peter C. Doyle

Department of Defense (DOD), which in 1981 initiated the Logistical and Material Automated Recorder System program. As a result, more than 50,000 manufacturers and suppliers must now use a standardized bar code identifying products shipped to military depots. Recently, the Automotive Industry Action Group, the Health Industry Bar Code Council, and the U.S. General Services Administration have each made the use of standard languages obligatory. The action by the automotive group alone means that about 20,000 vendors of automobile components are scrambling to bar-code their products using the same code language. Already, Chrysler (Highland Park, Mich.) is requiring that its 5500 direct material suppliers bar-code their parts; and GM and Ford expect to follow suit by year's end.

All these major groups are specifying the same standard—Code 39. Thus bar code labels used by, say, automotive suppliers will now also be readable by defense manufacturers with compatible hardware. With such widespread acceptance, Code 39 is eclipsing others. "It is the universal code" in the U.S., says Benjamin Nelson, bar code product manager of the label-printer maker Markem (Keene, N.H.)—just as the European Article Numbering code is almost universally accepted on the Continent.

Bar code scanning is by far the most widely used method of automatic identification, but it is not the only one. Ranking second in popularity is optical character recognition (OCR), which uses labels with stylized letters and numerals that are recognized by people as well as the scanner. Since an OCR scanner must "see" the entire character, a slight wavering may produce an inaccurate read. By contrast, bar codes are uniform from top to bottom, providing greater tolerance for scanner movement. They are thus better suited to high-volume industrial uses, where a large number of parts must be scanned quickly and accurately. When investigating automatic identification methods, the DOD found that bar-code scanning errs only about once in a million reads. OCR was found to misread about 50 times as often.

Magnetic ink character recognition uses encoded magnetic tape affixed to the product to carry identification data. The magnetized label must come into direct contact with the scanner, however—unlike laser bar code readers, which can scan at a distance. And in an industrial environment, the ID tags can be accidentally demagnetized, and thus rendered useless.

Another method of automatic identification is radio tracking, sometimes used in automobile plants to track car bodies through the assembly process. A small radio transmitter attached to the car body is triggered when it passes through a radio signal field. It then transmits its identification code to the station receiver. Radio tracking, however, is most advantageous when the product can't be scanned; it is generally too expensive for wide-scale application.

Bar coding not only combines reliability with low cost, it is adaptable to a wide variety of manufacturing settings because scanning can be accomplished in many different ways. At one extreme, fully automatic stationary scanners can be positioned along assembly lines and conveyors. At the other, pencil-size lightwand scanners, which illuminate with LEDs, may be attached to terminals for direct data entry, or be part of portable, belt-worn scanning systems that store data and later dump it into host computers.

Also popular for their portability are the new laser scanners, pistol-like devices that can scan at a distance of up to five feet. Unlike LED scanning wands, which must be manually moved across the code label, laser scanners are simply pointed at the label. An internal rotating mirror sweeps the laser beam across the code. In some models, the reflected beam sweeps rapidly enough to scan a label up to 40 times per second, assuring a good read. Hand-held laser scanners are more expensive than other types requiring operators. They also require more power, are heavier than lightwands, and are more fragile. But their speed is considered a major advantage in high-volume applications.

Although not yet in widespread use, machine vision methods also show promise for reading bar codes. The Identicon Division of Vertex Industries (Clifton, N.J.) markets a charge-coupled device (CCD) bar code reader that "comprehends" a bar code as a single image, rather than scanning across the bars in sequence. Since it "sees" with available light, the CCD does not need a special light source like conventional scanners. What's more, the cameralike reader can decipher poor-quality labels having only 30% contrast be tween bars and spaces, says Identicon, while lasers require more than 70% contrast.

Industrial bar coding is undergoing substantial market growth, due in large part to the push for standardization. International Resource Development (Norwalk, Conn.), a market research firm, forecasts $1.2 billion in sales of bar code equipment and systems this year, which is double 1984's total sales. By 1988 IRD expects sales to climb to $1.6 billion.

With such predictions, many new companies are entering the business of manufacturing and selling one or more components of bar code systems. The 1985–86 *Bar Code Manufacturers and Services Directory* (Peterboro, N.H.) lists 305 vendors, up from 220 in 1984–85 and about 140 the preceding year. In the late 1970s, only a handful of companies were involved in the technology. The largest was NCR, which has neglected industrial scanning despite its strong foothold in supermarket systems. Among the other notable participants are the following: Computer Identics (Canton, Mass.), which pioneered the bar coding of railroad freight cars; Intermec, which produced some of the first scanners and bar code printers; and Markem, which specialized in making label printers. Currently, Hewlett-Packard (Palo Alto, Cal.) claims to be the industry leader, with fiscal 1985 sales of $47.5 million in bar code products. But Intermec, the only company that produces bar code equipment exclusively, is close behind with annual sales of about $40 million.

New heavyweight contenders are shaking up the industry, says David Czaplicki, an Intermec executive who is also vice-president for educational development of Automatic Identification Manufacturers, the industry's trade association. Moore Business Forms (Glenview, Ill.) is expected to expand into bar coding, while Allen-Bradley, the Milwaukee, Wis., industrial control equipment maker, entered the field with its 1985 purchase of scanner maker Scope (Reston, Va.). "Allen-Bradley and Moore have the ability not only to penetrate the market but to become major forces," says Czaplicki. Just like the personal computer industry, he predicts, the bar code industry will polarize toward the more powerful manufacturers. □

Peter C. Doyle is a freelance writer based in Keene, N.H.

PUTTING TV SIGNALS UNDER LOCK AND KEY

Pay channels say their tricky new scrambling techniques are unbreakable

Owners of television receive-only (TVRO) earth stations are starting to have to pay for many of the services they once got for free. Responding largely to pressure from cable operators whose business has been threatened, more and more television programmers are beginning to scramble their signals to prevent unauthorized reception. And unlike the easy-to-crack scrambling systems used to conceal some transmissions in the past, the new techniques resemble the extremely secure measures used by banks to keep financial transactions private.

The move to scrambling gained momentum earlier this year when the country's two biggest pay programmers, Home Box Office (HBO) and Cinemax, began scrambling their signals. And now, about 30 of the 150 or so other programmers that transmit television shows via satellite have also begun to scramble or have announced plans to do so. Access to the scrambled shows requires several hundred dollars for a descrambling unit that plugs into the TV or the antenna—plus a monthly decoding fee to either the local cable company or the programmer.

There are currently 1 to 1.5 million TVRO systems in the U.S., and that number is expected to top 2 million this year, according to the Electronic Industries Association (Washington, D.C.). The home satellite antennas are most popular in remote areas that get poor reception of ordinary television broadcasts. Some 25% of TVROs, however, are installed in areas now served by cable. Scrambling is thus a potent tool in the cable industry's competition with home antennas.

by Rick Cook

While it is legal for individuals to receive programming directly from satellites, it is illegal to resell the signal without the programmer's consent. In violation of this rule, the managers of hotels, apartment buildings, and condominiums routinely tap satellite transmissions and sell the shows to their residents. In addition, many bars and restaurants try to draw customers by picking up sporting events for display on big-screen TVs. The potential for lost revenue is significant, both for the program originators such as HBO and for the local cable companies whose service is being bypassed.

The conflict will intensify with the arrival of new satellite technology. Currently, the use of TVRO antennas is limited by the need for a large dish, 6–10 feet across. But the next generation of satellites will transmit signals at higher frequencies, which can be picked up by antennas as small as 2 feet in diameter. Thus while site problems and zoning restrictions hamper the reception of present (C-band) transmissions, nearly everyone will have access to the high-frequency (Ku-band) signals. C-band TVRO can never be more than a nuisance to cable; Ku-band TVRO, however, could disrupt the industry.

Cable companies have been scrambling local signals for years, but with systems that rearrange the analog waveform and are fairly easy to break. A television signal is by nature extremely well defined; about 80% of the information in a television signal is determined by a standard format. Thus the would-be signal cracker knows in advance what many of the voltage levels will be and can use this information to decode the rest of the signal. The simplicity of this scheme has led to a proliferation of illegal descramblers that let consumers view programs without paying.

The new systems are much tougher, because they do not merely scramble; they encrypt, using a numerical "key" to mix up the information. Encryption requires that the television signal's continuously varying voltage be translated into a representative series of *1*s and *0*s. However, digitizing a television picture fast enough to keep up with its transmission requires equipment that's too expensive for home use. Therefore the new scrambling systems mix up the picture in the old analog style, while digitally encoding the sound.

"Audio you can encrypt cheaply," explains O. J. Hanas, vice-president and general manager of Oak Communications' satellite systems division (Rancho Bernardo, Cal.). "And if you deny the audio, especially for the en-

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tertainment networks, the video will be almost meaningless." Oak's Orion system is used by Canadian Satellite Communications (CanCom), and by five U.S. channels.

All the scramblers use conceptually similar encryption systems with multiple levels of keys. M/A-Com (Burlington, Mass.), whose VideoCipher system is by far the most popular, relies on the Data Encryption Standard (DES). Developed in the early 1970s, DES is commonly used to protect such sensitive information as automatic-teller transactions.

The DES algorithm divides the data stream into 64-bit packets and swaps each packet's left and right halves. The left half of the packet is combined with a 56-bit key using complex logic operations to generate a 32-bit string; this number is compared with the right half of the packet using an "exclusive OR" operation—which yields a *0* where the bits match, a *1* where they don't—to give a new series of 32 bits, which then replaces the right half of the packet. The process is repeated 16 times.

Although rumors to the contrary abound, there have been no substantiated reports that anyone—including the National Security Agency—has ever deciphered DES-encoded messages. "Cryptographers say you just can't crack this in real time," says Douglas Lindquist, director of marketing for M/A-Com's video products group.

For even greater security, encryption systems layer their keys like a Chinese puzzle box. In VideoCipher, the outermost layer is a key built into a custom integrated circuit in the descrambler unit. This key is used to decipher another key that is generated when the descrambler is turned on. This second key, which the programmer changes monthly by transmitting a special signal to paid-up subscribers, is stored in a battery-backed memory chip so it will not be lost even if the descrambler is turned off for months.

Before each show, the programmer transmits a program-specific key that is encoded using the monthly key. Then, as often as four times a second, the programmer sends yet another key that is encoded using the program key. It is this lower-level key that actually encodes the program.

This daisy chain of encoded keys is extremely secure. Breaking the program key descrambles the program only for a fraction of a second; to get more, the code breaker would have to either break a higher level key or break the low-level key again. Since none of the keys is ever available unencrypted, the cracker cannot just pick a key off the air. In addition, the descrambler's built-in key is itself encrypted and is used totally within a single integrated circuit. It is never put out onto the unit's internal wiring, where it could be picked off by a cracker with a logic probe.

All this has not stopped would-be crackers from trying to break the code. VideoCipher has become a favorite topic of discussion among computer system breakers and others who amuse themselves by dissecting and defeating complex systems. Already several companies advertise black boxes to defeat VideoCipher or books telling how to build such devices. So far, however, the underground has reported no system able to decode both the video and the sound.

The DES algorithm is on the State Department's list of sensitive technologies; thus DES-based equipment may not be sold outside the U.S. and Canada. M/A-Com is trying to get the rule modified so it can sell descramblers in Latin America and the Caribbean countries, which receive programming from American satellites. Oak, which uses a proprietary encryption scheme it claims is as secure as DES, is free to sell its scramblers overseas because export restrictions apply only to DES itself. England's Skychannel network, for example, uses Oak's Orion system.

The new scrambling systems can do other jobs besides keeping programs secure. The descrambler's built-in key serves as a kind of serial number, allowing individual addressing. Thus a programmer can divide its audience into segments, each receiving a different group of shows. An entertainment channel that carries news, movies, and sports, for example, could tag each as a separate tier; some subscribers could pay just for sports, some just for movies, others for all three. The M/A-Com and Oak systems allow for as many as 49 tiers.

Another potential use of tiering is to disseminate different information to various geographical areas such as time zones. "This could be very handy in Canada, where the laws prohibit reporting of election news before the polls close," says Oak's Hanas. CanCom already tiers its nationwide signal to give voters in the western provinces of Alberta, Manitoba, and British Columbia the results later than those in the east. Geographical tiering also helps black out sporting events in the cities where they are being played.

The descramblers' addressability also could be used for one-way mail service, with messages appearing on the screen of a particular subscriber. The first use of this will probably be as a collection tactic, with the cable company or program provider displaying a reminder to pay the bill. But gentler uses—such as having the programmer display "Happy birthday, John" on a subscriber's screen upon a telephoned request from a friend—are just as feasible.

The advent of scrambling has slowed the TVRO business. When it became apparent that some programmers actually would scramble, TVRO system sales fell off about 50% nationwide. It's generally cheaper to subscribe to a cable system and pay for the premium channels than to buy a satellite receiving station and descrambler.

Therefore sales of descramblers have started slow. "We don't expect a large increase in demand until more services start scrambling in the fall," says Jim Bunker, M/A-Com's senior vice-president for corporate marketing. As part of its agreement with HBO, M/A-Com has built up capacity to produce 50,000 descramblers a month and is licensing the technology to manufacturers of satellite receivers so they can build in descrambling. Already, several receiver manufacturers such as Birdview (Overland Park, Kans.) have announced that they will sell receivers with built-in decoders, and RCA is reportedly working on a television with a built-in decoder.

Demand for descramblers is unclear. There are still over 100 satellite channels in the U.S. that have not announced plans to scramble, and many of them may never do so. Some analysts and many TVRO makers predict that home earth-station owners will be satisfied with the unscrambled channels and won't pay the extra cost of a descrambler or the monthly fees for scrambled programming. On the other hand, the growing list of major entertainment programmers that have joined the scrambling camp leads other analysts to conclude that a descrambler will become a standard part of future TVRO stations.

Holding down sales is customers' recognition that descrambling is an expensive way to watch television. For starters, the descramblers themselves retail for \$250–\$600. And controversy has arisen regarding the high fees programmers charge for access to the monthly keys, without which a descrambler is useless. HBO, for example, costs \$12.95 a month, considerably more than cable companies charge their subscribers for the popular channel.

Such high prices have triggered some strong responses. The most flamboyant display of ire came in April, when an anonymous "Captain Midnight" managed to break into the transmission of an HBO movie; viewers found their screens filled with a message protesting the descrambling fee and hinting that other programmers would be similarly disrupted. (Captain Midnight's feat did not require cracking the scrambling code, simply a stronger signal than HBO's.) More seriously, allegations that satellite programmers have conspired with the cable industry to set prices artificially high have sparked a Justice Department investigation on possible restraint of free trade, and the introduction of a bill in Congress that would put a two-year moratorium on scrambling.

Ultimately, however, the scrambler manufacturers are confident that descramblers will be an accepted part of home satellite systems. "I hope that in two years, no one will discuss scrambling because it will be like an antenna," says Hanas. "You've got to have it, you put it in, and it works." □

Rick Cook is a freelance technology writer based in Phoenix.

RESOURCES

Information sources for topics covered in our feature articles

AI enters the mainstream, p. 16

Contact

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PERSPECTIVES

DNA tool promises better diagnostics

DNA probes have been hailed as potentially revolutionizing medical diagnostics by rapidly confirming the presence of a suspected disease-causing organism, or pathogen. So far, however, the probes have made only a minor impact on the diagnostics market. But a new probe technique developed by Cetus biotechnologists in Emeryville, Cal., may change all that.

Basically, a DNA probe is a solution consisting of single strands of normally two-stranded DNA. Because all DNA is structurally unique to its owner—whether a human, a flower, or a bacterium—the probe DNA can be designed so that it combines only with that of the organism of interest. When a probe containing a specific type of DNA (from a certain gene or bacterium, for example) is combined with a patient fluid sample containing the same genetic material, the two DNA segments bind together. The probe is often designed so that the binding produces a color change.

But what sounds simple in theory is much more difficult in practice. One common problem is that the pathogenic DNA in the patient's body fluid is highly diluted. The probe must therefore be extraordinarily sensitive—a requirement that often leads to false-positive test results. And because the probes require tedious manipulation of laboratory equipment and skilled interpretation of results, they are often considered too costly and time-consuming (up to 18 hours) for routine hospital use.

The Cetus probe, based on processes that take place naturally during cell reproduction, overcomes the dilution problem by using a natural enzyme to amplify the pathogen's DNA several hundred thousand times. If it proves out, this enzymatic sleight of hand could bring Cetus up to $200 million a year by 1990, according to analyst Robert Kupor at Cable, Howse & Ragen (Seattle). Besides infectious diseases, the probe could be used in a variety of tests that hinge on precise DNA identification—prenatal detection of genetic diseases, for example. In fact, the probe has already been used experimentally to spot the genetic blood disorder called sickle-cell anemia. In another recent development, researchers have shown that probes can prenatally detect some types of cancer-causing genes, permitting the expectant parents to take early steps toward control or treatment.

A complete DNA molecule consists of two parallel strands held together by smaller molecules in a zipper-like configuration. There are four kinds of "teeth" in the zipper, abbreviated A, T, G, and C. Tooth A on one side of the zipper binds only to tooth T on the other; similarly, G binds only with C. The result is that if the structure of one side of the zipper is known, that of its complement is also known.

The Cetus technology mimics a normal cell-division process by which an enzyme called DNA polymerase creates the DNA for a new cell. Traveling along the two-stranded DNA of the dividing cell, the enzyme assembles a third strand complementary to a strand of the original DNA, then a fourth strand complementary to the third; the two new strands unite to form a new DNA molecule. By adding the enzyme to the patient fluid sample, Cetus's technology repeats this process 20 times or more, doubling the amount of DNA each time.

Cetus's next step is to mate this amplification technology with an easy-to-use detection system. To that end, the company is working with Eastman Kodak (Rochester, N.Y.) to produce and market the new probe technology. Kodak will probably develop the system as part of its Ektachem line of automated diagnostic devices; barring hitches in FDA approval, commercialization is expected within about two years.

Although it is still in the early stages of development, the Kodak-Cetus probe would probably work like this: Micron-diameter latex spheres filled with europium (which glows red under ultraviolet light) would be laid on a membrane with holes just large enough for them to fall through. Half the spheres would be coated with DNA from the probe; the rest would carry the patient's fluid sample containing the amplified DNA. A positive result would be indicated by the widespread binding of the two types of spheres, which would prevent them from slipping through the membrane. The europium and an ultraviolet light source would provide quick visual confirmation of the result.

Despite analyst Kupor's enthusiasm for Cetus's technology, others anticipate some technical problems. For example, the copying enzyme could easily be poisoned (rendered useless by reacting with foreign molecules). "That isn't a problem in a laboratory," says biotechnology consultant George Keller, at Keller Research Services (Palmyra, Pa.), "but in a clinical setting, with different amounts of contaminating bacteria, I think it's going to be hard to get that target DNA clean enough to amplify time after time." But Cetus researcher Kary Mullis, who developed the technique, claims that the ability to amplify DNA hundreds of thousands of times permits the use of a very dilute sample together with enzyme concentrations high enough to overpower any contaminants.

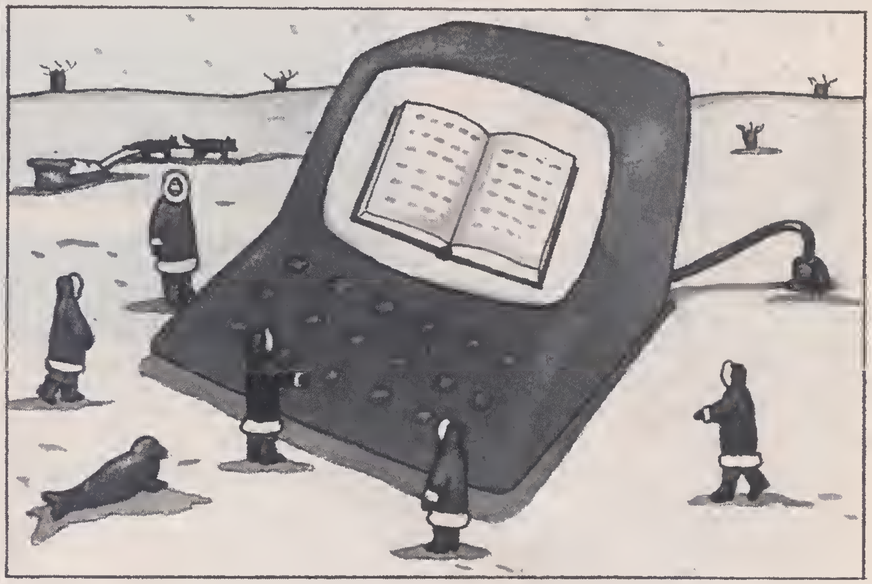
Others note DNA probes' stiff market competition from monoclonal antibodies—immune-system proteins that recognize and bind to markers, or antigens, on invading organisms and that are the basis of a growing number of medical diagnostic tests. "Most of the DNA probes are going to be several times more expensive than monoclonal antibody tests, which may cost less than $10," says Zholt Harsanyi, at the Washington, D.C., office of Porton International, a leading British biotechnology company. However, Cetus vice-president James Rurka expects the probes to ultimately sell for "under $5 for a simple infectious-disease test."

Cetus's Mullis acknowledges that monoclonals may remain the diagnostic of choice in many cases—especially when the pathogenic antigens are well-known and the organisms are present in large numbers. But Mullis also notes that many diseases (AIDS and bacterial diarrhea, for example) are characterized by a relatively small number of pathogens. And unlike DNA probes, antigen–antibody binding is reversible; that is, the antibodies may simply wash away during sample analysis, leading to a high false-negative rate. Nor can monoclonals be used for genetic screening or any other diagnostic that requires DNA analysis.

"I'm not claiming that Cetus has solved all the problems," says Kupor, "but they seem to have passed the major roadblocks. An analyst has to place bets. This is where I am willing to place mine at the moment." □

—David Holzman

Electronic education covers Alaska's backwoods



CATHARINE BENNETT

In an isolated village far above the Arctic Circle, a young Eskimo intently studies a computer screen filled with data, part of a University of Alaska (UA) business course delivered entirely by videotex. When she finishes the lesson, the student takes a test that is scored within seconds by a computer 1000 miles away in Anchorage. When she needs to do library research, she turns to an electronic card catalog—covering the UA library's entire collection—to find and order the books she needs. She also has access to the latest issues of professional and general-interest magazines delivered via one-way teletext, and to educational software sent to the local school's Apple II via low-powered TV signals.

That's the vision shaping up for LearnAlaska, the world's most technically advanced and geographically extensive electronic educational system. By the time she graduates, this student will earn a degree in business from UA without ever leaving her community, and might then stay on to administer her village's financial interests. Another student might study to be a nurse-practitioner, bringing modern medicine to the village for the first time.

Along with hundreds of other high school and college students in remote villages scattered over a territory a fifth the size of the entire "lower 48," they will take most of their courses via interactive videotex and telephone conference calls, supplemented by one-way television lectures and class discussions delivered by satellite from LearnAlaska's Anchorage studio.

Run jointly by UA and the state Department of Education, LearnAlaska is a response to the challenge of educating a scattered rural population. While almost 90% of Alaska's 400,000 residents live in the Anchorage-Fairbanks-Juneau triangle, the rest, mostly Indians and Eskimos, live in 365 communities scattered over 586,000 square miles of rugged terrain. About 85% of these communities are reachable only by water or air—and they are in need of nurse-practitioners, business managers, and other professionals.

LearnAlaska's heart is the world's largest teleconferencing network; during the 1984–85 school year, it handled 5782 conference calls involving a total of 38,400 users. Many of these calls were classes, but they also included administrative meetings, a statewide elementary-school contest resembling TV's *College Bowl*, an original radio-type play with student actors (and the audience) located at a variety of sites, and labor negotiations between the state and widely scattered unions.

With 4500 Apple IIs in classrooms and the nation's highest percentage of computers to students, Alaska is intensely interested in videotex, teletext, and software teledelivery. Videotex, which will operate over long-distance telephone lines between the remote sites and LearnAlaska's host computer, is beginning to deliver interactive training modules. UA officials expect videotex to quickly become an important adjunct to the LearnAlaska system, providing complete courses and supplemental material, electronic textbooks, and interactive testing for courses taught via audio conferencing.

Teletext and teledelivery of software, which got their start with LearnAlaska two years ago, are moving more slowly. Both programs use the vertical blanking interval (VBI)—the blank bar transmitted between frames of conventional TV signals—to send data over the educational TV network. The teletext and teledelivery signals are more sensitive to noise than are regular TV picture signals, so each of the state's rebroadcast stations must be tested and adjusted separately to deliver them properly.

In spite of these problems, LearnAlaska remains interested in both systems, because they promise inexpensive channels for one-way delivery of large amounts of information. Operations manager Charles S. Hickman says several ambitious proposals such as the UA card catalog—which will be one of the largest teletext projects ever undertaken in terms of data delivered—have already been submitted to the state legislature for funding. In the meantime, the VBI has been used to deliver teletext editions of popular magazines and samples of educational software to several remote sites in the LearnAlaska network.

LearnAlaska also makes heavy use of two electronic mail systems: one is based at the University of Alaska, and the other, run by the Department of

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thing, though: "Any time the others start producing 4-Mb chips, we'll be ready to start," says Matsushita's Horiuchi.

Nonetheless, the technology of the 4-Mb DRAMs is still far from routine. Most critical is the capacitor used in the memory cells to store the electric charges representing bits of data. The flat, or "planar," capacitors in early, low-density integrated-circuit memories required a substantial amount of the chip's surface area. As the number of memory cells increased, capacitor size and circuit line width had to be

trench-type 1-Mb device.

But trench capacitors will probably be necessary at the 4-Mb level. NEC's prototype 4-Mb DRAM uses a unique structure in which the charge is stored on the inside of the trench rather than in the substrate, thus reducing vulnerability to so-called soft errors. These random errors are caused by impacts from high-energy alpha particles in the earth's background radiation, which cause charge depletion in the minuscule memory cells.

The other major technical challenge, that of etching and depositing

machine is 10 times the cost of an E-beam machine," says Matsushita's Horiuchi.

These new manufacturing methods will significantly raise fabrication costs for coming generations of memory chips. Thus, when Hitachi set up an ultralarge-scale integration lab within its Central Research Laboratory near Tokyo, an impressive target was needed to get management approval of the massive budget required, according to Sunami. The target they chose was impressive indeed: the creation of a 64-megabit DRAM. ☐ —***Robert Poe***

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Education, connects the state's 52 school districts. These networks have almost completely replaced voice telephone for administrative communications, mainly because their store-and-forward capability allows users to receive and send messages at their convenience—a vital feature in a state that spans four time zones. □

—*G. Berton Latamore*

Japan eyes the lead in 4-megabit memory chips

Although sample shipments of 1-megabit memory chips have only just begun, Japanese semiconductor makers are already jockeying for position in the 4-megabit sweepstakes. The competition is stiff and the race is close: "All the big Japanese makers are at about the same level technologically," says Shiro Horiuchi, director of Matsushita Electric's Advanced Devices Laboratory. Probably the only clear winner in this intense rivalry will be memory buyers as prices for megabit chips tumble in the face of fierce competition.

Much of the technology needed for 4-Mb dynamic random-access memories (DRAMs) is already known, so success will most likely come from refining existing designs and improving production processes. Two Japanese companies, NEC and Toshiba, have already built experimental devices and presented papers on them at the 1986 International Solid-State Circuits Conference. The rest aren't conceding anything, though: "Any time the others start producing 4-Mb chips, we'll be ready to start," says Matsushita's Horiuchi.

Nonetheless, the technology of the 4-Mb DRAMs is still far from routine. Most critical is the capacitor used in the memory cells to store the electric charges representing bits of data. The flat, or "planar," capacitors in early, low-density integrated-circuit memories required a substantial amount of the chip's surface area. As the number of memory cells increased, capacitor size and circuit line width had to be decreased. One problem with this approach was that as the capacitors shrank, they were no longer able to store sufficient charge. And as circuit lines became narrower, they became increasingly difficult to etch on the chip surface.

One solution, favored by Fujitsu, is to create capacitors in silicon layers deposited on top of some of the current-carrying lines, rather than on the chip's surface. These "stacked" capacitors do not compete directly for space with the circuitry, yet they are big enough to store the necessary charge.

In the second approach, favored by NEC, tiny holes, or "trenches," a few millionths of an inch deep are etched into the silicon substrate, then filled with another silicon layer. The area of contact between substrate and deposited layer—which is where the stored charge gathers—is thus increased while the chip surface used remains small.

Though the trench capacitor will undoubtedly offer the highest density, some designers question the need for it. "We made a prototype 1-Mb chip using trench capacitors," says Hitachi Central Laboratory's Hideo Sunami, one of the pioneers of the technique, "but when a larger chip size was proposed, we found we didn't need it." Hitachi's prototype was based on a 16-pin package, but the industry standard was eventually set at 18 pins to permit an extra address line. Thus the company took the conservative route and stayed with planar capacitors. Toshiba and Matsushita are also using the planar approach at this level; NEC is the only company to have developed a trench-type 1-Mb device.

But trench capacitors will probably be necessary at the 4-Mb level. NEC's prototype 4-Mb DRAM uses a unique structure in which the charge is stored on the inside of the trench rather than in the substrate, thus reducing vulnerability to so-called soft errors. These random errors are caused by impacts from high-energy alpha particles in the earth's background radiation, which cause charge depletion in the minuscule memory cells.

The other major technical challenge, that of etching and depositing narrower lines on the chip's surface, is also being addressed in a variety of ways. For 1-Mb chips, lines as narrow as 1.2 microns are needed, while the 4-Mb variety requires 0.8-micron lines. But submicron distances begin to approach the wavelength of light, so precise control of line width becomes impossible with conventional lithographic techniques.

A possible solution is to use light with a shorter wavelength or direct-writing electron beam machines. The electron beam technique offers far more precision, but the entire surface of the chip cannot be exposed at once. Instead, the narrow beam must "write" the pattern on the surface line by line, guided by a computer. "The method is going to be too slow for mass production," claims Matsushita's Horiuchi. Electron beam machines are used, however, to make photomasks—the original patterns, corresponding to a photographic negative, that are etched on coated glass or quartz and then projected on the chip's surface during the production process.

X-ray lithography holds more potential for mass production, since it offers fine line resolution and permits an entire wafer to be exposed at once. Special photomasks, with patterns formed of materials such as gold, are necessary, and synchronous orbital resonance (SOR) machines are being built to produce the powerful radiation needed. One of the most promising new techniques, electron cyclotron resonance, allows ions to etch at lower temperatures and pressures, reducing the effect on surrounding areas. But the equipment is expensive: "An SOR machine is 10 times the cost of an E-beam machine," says Matsushita's Horiuchi.

These new manufacturing methods will significantly raise fabrication costs for coming generations of memory chips. Thus, when Hitachi set up an ultralarge-scale integration lab within its Central Research Laboratory near Tokyo, an impressive target was needed to get management approval of the massive budget required, according to Sunami. The target they chose was impressive indeed: the creation of a 64-megabit DRAM. □ —***Robert Poe***

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TECHSTARTS

Anadigics:

EASING GaAs PAINS

Until recently, chips made from gallium arsenide (GaAs) have been available in the U.S. from just a handful of companies, at prices as high as the chips were scarce. But the creation of several new commercial GaAs foundries—by companies such as Ford Microelectronics, Vitesse, and now Anadigics—promises to make GaAs devices more plentiful and affordable. Anadigics intends to produce microwave amplifiers, analog-to-digital converters, and other signal-processing chips for the defense, telecommunications, and industrial instrumentation markets. Consequently, it will be competing with the few established GaAs manufacturers like Gigabit Logic and Harris Semiconductor, as well as with other newcomers to the field.

Financing: $9.7 million in venture capital from Alan Patricof Associates, Alex Brown & Sons, Fairfield Ventures, General Electric Venture Capital, Orange Nassau Capital, Rothschild Inc., and Smith Barney Harris Upham & Co.

Management: Cofounders Ronald Rosenzweig (president and CEO) and George Gilbert (executive VP and COO) also cofounded Microwave Semiconductor, a silicon and GaAs chip maker now owned by Siemens of West Germany. Rosenzweig was president and CEO, and Gilbert was executive VP. Charles Huang (VP of engineering) directed GaAs research and fabrication for Avantek, a GaAs chip maker.

Location: 35 Technology Dr., Warren, NJ 07060, (201) 668–5000.

Founded: January 1985.

Counterpoint Computers:

PRODUCT LINE SHARES PARTS

With so many special-purpose computers on the market—from engineering workstations streamlined for high-speed calculation to order-processing systems that log many simultaneous short transactions—companies can end up owning several incompatible machines. Counterpoint's alternative is a computer family that includes an array of specialized equipment, such as high-resolution graphics displays and database servers, that customers can match to specific applications while maintaining overall compatibility. It is developing the product line jointly with three corporate partners—AT&T Information Systems (Morristown, N.J.), Kyocera (Kyoto, Japan), and British & Commonwealth (London)—and may market it with them as well. Because plans call for such a range of equipment, Counterpoint will face a variety of competitors, such as Apollo in the engineering market and Convergent Technologies in the office market.

Financing: $18 million in venture capital from investors including AT&T Information Systems, Kyocera, British & Commonwealth, Mayfield Partners, Hambrecht & Quist, Arthur Rock & Co., Oak Investment Partners, Gartmore Information and Financial Trust, and Mohr Davidow Ventures.

Management: Founders Pauline Alker (president and CEO) and Frederick Kiremidjian (VP of engineering) defected from computer maker Convergent Technologies, where Alker was VP of marketing and Kiremidjian was in charge of workstation design. Paul Rosenfeld (VP of marketing) was previously a marketing manager for Rolm, and Kenneth Cannizzaro (VP of North American sales) was a sales manager for Masscomp.

Location: 2127 Ringwood Ave., San Jose, CA 95131, (408) 434–0190.

Founded: May 1984.

Counterpoint's Pauline Alker with a high-resolution graphics display, one of many specialized options in the company's planned computer line.

Synbiotics:

TESTING WITH MAbs

Like antibodies produced naturally by the immune system, monoclonal antibodies (MAbs) recognize and bond with specific proteins, including those in viruses, bacteria, tumor cells, and drugs. As a result, they are being used both as a diagnostic tool to spot the existence of particular cells in tissue or blood samples and to deliver drugs selectively to specific targets. Synbiotics, a spinoff of Scripps-Miles (a joint venture between the Scripps Clinic and Miles Laboratories), makes and sells a line of veterinary diagnostic kits, including tests for feline leukemia and canine heartworm and rheumatoid arthritis. It makes a line of human diagnostic kits, including tests for chlamydia and respiratory allergies, for Behring Diagnostics; it also makes MAbs for Miles Laboratories that are used to monitor patients' metabolism of drugs. In the young but fast-growing market for MAbs, Synbiotics competes with such companies as Cetus in human diagnostics and Cambridge BioScience in veterinary applications.

Financing: $3.4 million in net proceeds from a public stock offering of 1 million shares in August 1983. The OTC stock symbol is SBIO. $8.5 million from a limited R&D partnership established in December 1985 by R&D Funding, an affiliate of Prudential-Bache Securities.

Management: Founders Edward Maggio (president and CEO) and Daniel Cain (executive VP and CFO) came from Scripps-Miles, where Maggio was VP in charge of R&D and Cain was VP in charge of finances. Morton Vodian, director of R&D, headed an immunoassay R&D group at SmithKline/Beckman Diagnostics. Gregory Soulds, director of marketing and business development, held a similar position at International Immunology.

Location: 11011 Via Frontera, San Diego, CA 92127, (619) 451–3770.

Founded: March 1982.

RICK BROWNE

FIGHTING CANCER THROUGH IMMUNOLOGY

New therapies offer hope and long-term opportunities

Biochemical companies are aiming to tap a large potential market for cancer treatments with a number of new substances that have already demonstrated important advances. Cancer is responsible for about one out of five deaths in the U.S., making it the second most common cause of death (next to heart disease). Some $400 million annually is now spent on drugs to treat cancer, according to the American Cancer Society.

Progress in treating cancer to date has rested primarily on surgery, radiation, and chemotherapy. These techniques are not effective in treating all types of cancer, however, and they may not help patients whose illness is too far advanced. But such therapies may be improved with the concurrent use of newer approaches that are based on an increased understanding of the body's immune system and the application of biotechnology techniques for the large-scale production of immune-system proteins.

Interleukin-2 (IL-2), for instance, activates tumor-attacking white blood cells crucial to the immune system's operation. Tumor necrosis factor kills cancer cells directly, and colony-stimulating factor enhances the growth and development of certain white blood cells that help protect the body against bacteria and tumor cells. Work is also proceeding on toxins linked to monoclonal antibodies, which, unlike chemotherapy, can find and attack specific cancer cells without destroying healthy cells in the rest of the body.

by James McCamant

Several genetic engineering and pharmaceutical companies—including Cetus (Emeryville, Cal.), Ribi Immunochem Research (Hamilton, Mont.), and Imre (Seattle)—are involved in testing such approaches. Investors should keep in mind that these companies are likely to experience marginal profits or net losses over the several years it may take to get Food and Drug Administration (FDA) approval. Even after commercialization, uncertainties will remain—the extent to which the company has secured the necessary patents, for example—that will influence the market for individual products.

Cetus (OTC: CTUS), the second largest biotechnology company (after Genentech), is using its considerable resources to support experimentation in a broad range of potential cancer therapeutics. The firm produces its own patented version of IL-2; this drug is now in clinical trials and is expected by Cetus to receive FDA approval by 1988. Cetus also has programs to develop cancer-killing monoclonal antibodies, tumor necrosis factor, and colony-stimulating factor. By establishing a joint venture with Ben Venue (Bedford, Ohio) to sell generic cancer drugs, Cetus has been able to develop a sales force in the field prior to getting FDA approval for its own products.

Revenues in 1985 were $57.2 million, yielding profits of $1.2 million and earnings per share of 5¢. The previous year's revenues were $46.2 million, with $992,000 in profits and 4¢ earnings per share.

Ribi (OTC: RIBI) specializes in producing antitumor agents that stimulate the immune system. One such product, called Ribigen, has been approved by the U.S. Department of Agriculture for cancer treatment of horses and cattle. Two other drugs for humans, Detox and Ovamid, are under development. Detox is now in clinical trials. Although findings have not yet been publicized, this drug appears to work best when injected directly into solid tumors that are easily accessible, such as head, neck, and skin cancers, in contrast with cancer cells that circulate in the bloodstream. Ovamid, which has some similarity to Detox, is intended for cervical cancer; it will enter clinical trials later this year.

The company had $980,000 in revenues in 1985, up from $913,000 the previous year. But the net loss of $287,000 and a 4¢ loss per share in 1984 increased to a loss of $478,000 and a loss per share of 6¢ in 1985.

Based on the observation that excessive amounts of immune complexes (a form of antibody) turn off the body's immune system, **Imre** (OTC: IMRE) produces a dialysis-like device that removes such substances from the blood. This process has achieved promising experimental results with breast cancer and Kaposi's sarcoma (associated with AIDS). FDA approval is expected this year for marketing the device to treat ITP, an immune disease that interferes with blood clotting. Meanwhile, Imre is pursuing clinical trials to demonstrate its efficacy against cancer.

Revenues in 1985 were $267,000, with a net loss of $2.4 million and a 30¢ loss per share; 1984 revenues were $357,000, with a $2 million loss and a loss per share of 28¢. □

STAN JENNINGS

Cetus's David F. Mark, Shi-Da Yu Lu, and Leo S. Lin receive 1986 Inventor of the Year Award for work on Interleukin-2.

James McCamant is editor of the Medical Technology Stock Letter *in San Francisco.*

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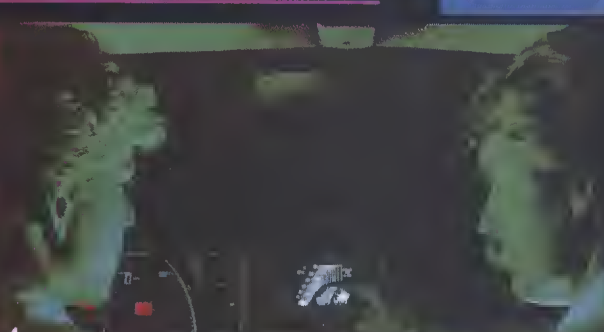

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